Appendix D
Water Quantity Assessment Report

WATER QUANTITY ASSESSMENT

WRIA 40A (Squilchuck/Stemilt)

FINAL Draft – FEBRUARY, 2007

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Submitted to:
WRIA 40A Technical Subcommittee

Phase II
WATER QUANTITY ASSESSMENT

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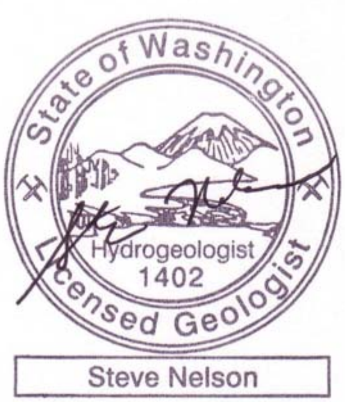

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Section 1 - Introduction

1.0 REGULATIONS AND APPLICATIONS

In 1998, the Washington State Legislature adopted the Watershed Management Act (Act) codified as Chapter 90.82 RCW. Watershed plans are developed at the local level by residents of the area with guidance and involvement by the Washington State Department of Ecology (Ecology) rather than being developed and directed by Ecology with local resident support.

Watershed planning is conducted using the boundaries of the Water Resource Inventory Areas (WRIA) established by Washington Administrative code (WAC) Chapter 173-500. The legislature made a special provision relating to WRIA 40A as follows:

> WRIA 40 shall be divided such that the portion of the WRIA located entirely within the Stemilt and Squilchuck sub-basins shall be considered WRIA 40A and the remaining portion shall be 40B. Planning may be conducted separately for WRIA 40A and WRIA 40B. (RCW 90.82.060(2).

This provision does not consider the significant hydraulic association of sub-basins adjacent to and between the Stemilt and Squilchuck sub-basins. These sub-basins exchange water with the Stemilt and Squilchuck basins via groundwater seepage and transfer and application of irrigation water. Consequently, the watershed planning area was enlarged to include the Malaga and Wenatchee Heights sub-basins within the WRIA 40A assessment. The study area is shown in **Figure 2-1**.

The Watershed Planning Process established by the Act includes the following four phases: Phase 1- Organization; Phase 2 – Assessment; Phase 3 – Planning and Phase 4 – Implementation. RCW 90.82 requires Phase 2 assessments to include a water quantity element, but water quality, instream flow, habitat, and water storage assessments are optional. This report meets the requirement for Phase 2-Water Quantity Assessment. The WRIA 40A planning unit elected not to include the water quality, instream flow and habitat elements but elected to include the water storage assessment element (in preparation). The quantity assessment compiles water resource quantity and use data to improve local knowledge about water resource issues and concerns and to develop the tools necessary to support decision-making regarding management recommendations to address local concerns. RH2 Engineering, Inc. (RH2) was contracted by the Chelan County Natural Resources Department (CCNR) to conduct the technical assessments. A technical subcommittee consisting of Planning Committee members and interested citizens was created to work with RH2 and provide local information and review of technical elements.

1.1 PHASE 2 ASSESSMENT OBJECTIVES

The Act allows planning units to apply for State funding for various elements of the watershed planning process. Because WRIA 40A was split from the remainder of WRIA 40, the funds available are also split. WRIA 40A is eligible for one-fourth of the funding available for the entire WRIA40 (A & B) (see RCW 90.82.060). WRIA 40A consists primarily of the Squilchuck and Stemilt sub-basins and two adjacent, hydraulically similar and connected sub-basins.

The Act requires that the planning unit conduct a water quantity assessment to examine water supply and use and develop strategies for future use. In addition to the required water quantity assessment, the WRIA 40A planning unit elected to simultaneously conduct the optional multi-purpose water storage assessment.

RCW 90.82.070 addresses the requirements of the water quantity assessment, stating that:

> (1) The assessment shall include:
>
> > (a) An estimate of the surface and groundwater present in the management area;
> >
> > (b) An estimate of the surface and groundwater available in the management area, taking into account seasonal and other variations;
> >
> > (c) An estimate of the water in the management area represented by claims in the water rights claims registry, water use permits, certificated rights, existing minimum instream flow rules, federally reserved rights, and any other rights to water;
> >
> > (d) An estimate of the surface and groundwater actually being used in the management area;
> >
> > (e) An estimate of the water needed in the future for use in the management area;
> >
> > (f) An identification of the location of areas where aquifers are known to recharge surface bodies of water and areas known to provide for the recharge of aquifers from the surface; and
> >
> > (g) An estimate of the surface and groundwater available for further appropriation, taking into account the minimum instream flows adopted by rule or to be adopted by rule under this chapter for streams in the management area including the data necessary to evaluate necessary flows for fish.

The Legislature stated the following regarding the purpose of the Act.

> The purpose of this chapter is to develop a more thorough and cooperative method of determining what the current water resource situation is in each water resource inventory area of the state and to provide local citizens with the maximum possible input concerning their goals and objectives for water resources management and development (RCW 90.82.005).

Perhaps the most significant goal of the watershed assessment is to provide the most thorough understanding possible of the current water resources situation in WRIA 40A, consistent with the Legislature's direction. A thorough and accurate understanding of the water resource situation provides a strong foundation for any future efforts related to water resource management, whether it is to guide additional studies or obtain funding for a needed water resources project.

One of RH2's goals in conducting the watershed assessment is to identify what is known about the water resources of WRIA 40A and to identify where there are significant gaps in the data. RH2 has identified and compiled data gaps, and described their significance on the quantity assessment.

As stated previously, the Legislature identified several required elements of the watershed assessment. These include the evaluation of "strategies for increasing water supplies in the management area, which may include, but are not limited to, increasing water supplies through water conservation, water reuse, the use of reclaimed water, voluntary water transfers, aquifer recharge and recovery, additional water allocations, or additional water storage and water storage enhancements."

In order to evaluate each of these strategies, a thorough understanding of the water resources of a given area is essential. Members of the WRIA 40A planning unit expressed a great deal of interest in increasing the amount and dependability of water storage in the watershed, and both strategies are identified in the Act. However, it is likely that, before providing funding for feasibility studies, design, or construction of additional water storage facilities, the funding entity would likely want assurance that the development of additional storage is supported by data from the water quantity assessment, and that additional storage is a strategy that makes sense for the area from a technical standpoint. Is water available for such storage? Is there a suitable site for the storage of the water? Can the water be stored and used without impairing existing water right holders? Is the development of new storage the best alternative of the strategies evaluated? Would it make more sense, for example, to focus on water conservation or reuse? The water quantity assessment is designed to support such questions and provide a technically sound foundation for future water resource management decisions in WRIA 40A.

1.2 WRIA 40A IMPLEMENTATION GOALS

RH2 obtained results of a ranking of the Planning Unit's watershed planning objectives and desired future conditions that was developed during Phase 1 of the watershed planning process conducted in 2005 and during initial meetings in Phase 2 held in May and June of

2006. The items were ranked according to their level of importance, with the ranking levels of very, somewhat, moderately, slightly and not.

Based on those results, the Planning Unit developed the following Implementation Goals for WRIA 40A, and listed in their general order of ranking.

1. Upgrade existing water reservoir storage and irrigation water distribution systems for water conservation and continued safety protection (fire suppression water). (Note: The availability of fire suppression water protects the watershed and natural resources within the WRIA. If this area were to experience a catastrophic wildfire, it would drastically impact the water balance in the area because of changes to runoff and evapotranspiration that would occur.)

2. Implement cost-effective new water storage projects in both the Stemilt and Squilchuck Creek watershed to sustain flow during the agricultural water use period and the fall low flow period.

3. Obtain needed data to enhance the water balance developed in the quantity assessment as part of the watershed planning effort and consider the water balance in all decisions related to water supply in the WRIA 40A study area.

4. Evaluate artificial snow-making and reservoir construction at the Mission Ridge Winter Sports Area to determine opportunities for enhancing water delivery in terms of timing and flow in the Squilchuck Creek watershed.

5. Where feasible, transfer existing, interruptible Columbia River water rights to non-interruptible sources. Coordinate with the Department of Ecology's Columbia River Initiative to ensure this issue is adequately addressed in that effort.

6. Where feasible, provide domestic water from the regional water supply to support future residential and industrial development in WRIA 40A.

7. Work with Chelan County Natural Resources and other local and State agencies to protect critical areas (wetland, riparian and groundwater recharge).

8. Improve diversion of water from Squilchuck Creek and Lake Creek to Beehive Reservoir.

9. Build a pipeline to transmit water from Beehive Reservoir to Squilchuck Creek.

Section 2 – WRIA 40A Characteristics

The area occupied by WRIA 40A (also referred in this report as the "watershed," "basin" or "management area") comprises 49,100 acres (76.7 square miles) bounded by the Columbia River to the north, sub-basins of the Wenatchee and Columbia Rivers to the west (Mission Creek, Number 2 Canyon, Dry Gulch), Naneum Ridge to the south and Jumpoff Ridge to the east. The two primary streams in WRIA 40A, Squilchuck and Stemilt Creeks, are tributaries to the Columbia River. The management area consists of four sub-basins: Squilchuck; Stemilt; Malaga; and Wenatchee Heights (**Figure 2-1**). Characteristics are summarized in **Table 2-1**. Approximately 8 percent of WRIA 40A lies within Kittitas County.

WRIA 40A is the smallest of all WRIAs in the state and by comparison, is 5 percent of the total area of the Wenatchee River Watershed (WRIA 45). However, the average population density of WRIA 40A (50 per square mile) exceeds that of WRIA 45 (39 per square mile). Eighty percent of the water used in WRIA 40A households originates in the watershed.

Elevation in WRIA 40A ranges from 605 feet at the Columbia River to 6,887 feet at Mission Peak. Dominant landforms consist of high ridges and steep cliffs that surround large basins, knobs and depressions, deeply incised channels, gravel terraces and the Wenatchee Heights mesa. Average annual precipitation ranges from 8 inches in the lower elevations to 32 inches in the highest elevations and promotes shrub-steppe and sub-alpine forest vegetation, respectively.

The 2000 Washington State Census data indicate a population of 3,770 for WRIA 40A. **Section 6** discusses population growth rates projected to 2025. Most residents work outside of WRIA 40A in metropolitan Wenatchee and East Wenatchee (Douglas County). The Malaga sub-basin has the highest population density, followed by the Squilchuck, Stemilt and Wenatchee Heights sub-basins. Tree fruit orchards and commercial forestry are the predominant land use in the basin. Residential, recreational and industrial are also important land uses. Recreational use includes nearly 100,000 annual visitors to Mission Ridge Ski Area (USFS, 1998). Underground gold mining and hydroelectric power generation occurred along the lower Squilchuck Creek during the early 1900s.

2.0 SUB-BASINS

Each of the four sub-basins in WRIA 40A have distinct elevation, geology, weather and vegetation characteristics. Approximately 47 percent of WRIA 40A is above an elevation of 3,000 feet; 38 percent of the basin lies between an elevation 1,500 and 3,000 feet; and 15 percent lies below elevations of 1,500 feet. **Table 2-1** summarizes sub-basin characteristics. The following text summarizes the sub-basins from north to south.

Squilchuck Sub-basin
The Squilchuck sub-basin has the second largest area and the highest elevation in WRIA 40A at Mission Peak. Much of the upper portion of this sub-basin consists of high ridges with northern and eastern facing bedrock escarpments above extensive older landslides. The near vertical faces of these slopes enclose a broad bowl in the upper watershed with knobs and depressions on its floor that have been incised by tributaries of upper Squilchuck Creek. Lower Squilchuck Creek and its tributary Pitcher Creek deeply incise the Squilchuck sub-basin, and small landslides lie along the sidewalls of these canyons. Wheeler Hill, a broad and relatively steeply-plunging ridge, divides the Squilchuck sub-basin from the Stemilt sub-basin. At lower elevations, the ridge widens into a gently-sloping mesa (Wenatchee Heights) that extends to the Columbia River. The Squilchuck sub-basin terminates at the confluence with the Columbia River along a narrow, ½-mile wide boundary.

Stemilt Sub-basin
The Stemilt sub-basin has the largest area and the second highest elevation in WRIA 40A at Wenatchee Mountain. The upper Stemilt sub-basin is enclosed by the bedrock escarpments of Naneum Ridge, Jumpoff Ridge and Wheeler Ridge into an elongate bowl, which contains knobs and depressions that are deeply incised by branches and tributaries of Stemilt Creek. Several deeply incised tributary canyons drain Wheeler Ridge and Stemilt Ridge, and lower Stemilt Creek has incised the sub-basin floor into a steep-walled canyon. Stemilt Hill divides the Stemilt sub-basin from the Malaga sub-basin, along an indistinct boundary where it joins Jumpoff Ridge. The Stemilt sub-basin terminates at the confluence with the Columbia River along a narrow, ½-mile wide boundary.

Malaga Sub-basin
The Malaga sub-basin has the third largest area and third highest elevation in WRIA 40A at Jumpoff Ridge. Terrain in higher elevations is hummocky with numerous knobs and depressions. Most of the sub-basin lies below 2,000 feet, where relatively flat gravel terraces dominate the topography within 1 to 2 miles of the river. Stemilt Hill forms a subtle divide that separates the Stemilt and Malaga sub-basins to the west, and Jumpoff Ridge forms a precipitous eastern boundary to the sub-basin. There are no well defined drainage channels within the Malaga sub-basin, which broadly terminates along a 5-mile wide boundary with the Columbia River.

Wenatchee Heights Sub-basin
The Wenatchee Heights sub-basin, between Stemilt and Squilchuck sub-basins, has the smallest area and lowest maximum elevation in WRIA 40A at Wenatchee Heights. This sub-basin drains most of Wenatchee Heights and consists of a gently sloping mesa and deeply incised drainages that flow directly to the Columbia River. The sub-basin broadly terminates along 2 miles of the Columbia River via a narrow strip of gravel terrace.

Table 2-1.
Sub-basin Characteristics, WRIA 40A

Sub-basin	Area (acres)	Minimum Elevation (feet)	Maximum Elevation (feet)
Squilchuck	17,600	~640	6,887
Stemilt	21,430	~640	6,742
Malaga	8,490	~640	3,720
Wenatchee Heights	2,200	~640	2,560

2.1 LANDCOVER AND LAND USE

Land cover in the Squilchuck and Stemilt sub-basins ranges from shrub-steppe in the lower and middle elevations to forest and bare rock outcrops in the higher elevations. Crop cover that is mostly comprised of orchards is extensive in both basins (**Figure 4-2**). The Malaga sub-basin is dominated by shrub-steppe land cover with extensive orchards and relatively dense urban cover in the lower elevations within about 1 mile of the Columbia River. Shrub-steppe land cover in the Wenatchee Heights sub-basin is mostly confined to slopes that are too steep to be used for agriculture. Most relatively flat areas in this sub-basin are covered by orchard.

Current zoning information from the Chelan County Planning Department was examined to determine the approximate land use in each sub-basin (**Figure 2-2**). About 73 percent of land use in the Squilchuck sub-basin is zoned Rural Residential/Resource (2.5, 5, 10 and 20 acre minimum lot size), 25 percent as Commercial Forestry, 1 percent is a State Park and 1 percent located near the mouth of Squilchuck Creek lies within the Wenatchee Urban Growth Area. Approximately 22 percent of the Stemilt sub-basin is zoned Rural Residential/Resource, 19 percent as Commercial Agriculture, 58 percent as Commercial Forestry, and less than 100 acres of Rural Industrial land use exists near the mouth of Stemilt Creek. About 53 percent of the Malaga sub-basin is zoned Rural Residential/Resource which includes some Rural Recreational/Resource, 41 percent is zoned as Commercial Agriculture and about 6 percent as Rural Industrial located within ½-mile of the Columbia River. Ongoing planning revision efforts in the Malaga sub-basin include the re-designation of land use in the vicinity of Malaga to Local Areas of More Intensive Rural Development (LAMIRD) that affects the region within about 1 mile of the Columbia River (Chelan County, 2006). Land use in the Wenatchee Heights sub-basin is approximately 60 percent Rural Residential/Resource and 40 percent Commercial Agriculture.

2.2 HYDROLOGY

Squilchuck and Stemilt Creeks, the major surface water features in WRIA 40A, discharge directly into the Columbia River. Approximately 65 percent of annual water flow in these two streams derives from snowmelt during April to July. Some reaches of these mostly perennial streams are consistently dry in late summer and fall, and Stemilt Creek was historically dry on occasion before irrigation diversion (United States Forest Service [USFS], 1998; Andonaegui, 2001). The creeks periodically flood during high spring time snowmelt and during episodic high intensity storms. As recently as the spring of 2006, flooding in Stemilt Creek damaged road crossings, irrigation infrastructure and breached a levee near its mouth. During November 2006, an unusually wet month, streamflows only increased moderately following several storm events and flooding did not occur as in other drainages such as the Wenatchee River, indicating that excessive runoff in the smaller watershed is determined by local, rather than regional precipitation events. The most serious flood on record occurred in Squilchuck Creek, in September 1925 when flash flooding from a high intensity storm resulted in 16 fatalities and significant damage to the Appleyard rail terminal and other residential and commercial structures (Wenatchee Daily World, 1925). The hydrologic characteristics of the watershed has not changed substantially since 1925. Intense peak flows such as the 1925 flood will recur, and likely will have greater impact due to the greater density of population and infrastructure (roads, bridges, reservoirs).

Squilchuck Creek is approximately 10.6 miles long with three perennial tributaries: Miners Run Creek, Lake Creek and Upper Squilchuck Creek (USFS, 1998). Numerous intermittent tributaries flow during periods of snowmelt and during high intensity thunderstorms (USFS, 1998). Springs are common in the upper reaches of Squilchuck Creek and support baseflow (Wooldridge, 1994). About 27 percent of the Squilchuck Creek watershed is in public ownership (Northwest Power Planning and Conservation Council, 2004).

Stemilt Creek is approximately 12.4 miles long with four perennial tributaries: Orr (also called Westerly Northwest Branch); Middle (also called Easterly Northwest Branch); Little Stemilt (also called Southeast Branch); and Big Stemilt (also called Easterly Southeast Branch) Creeks (Williams et al., 1975). A few springs discharge into lower Stemilt Creek (Andonaegui, 2001). About 58 percent of the Stemilt Creek watershed is in public ownership (Northwest Power Planning and Conservation Council, 2004).

Continuous streamflow data for WRIA 40A do not exist. Short term, occasional streamflow monitoring was conducted in 1987, 1990, 1992, 1993, and 1994 (Clausing, 1984; Chelan County Conservation District, 1990; Wooldridge, 1994). The Washington Department of Fish and Wildlife (WDFW) conducted streamflow measurements at the mouths of Squilchuck and Stemilt Creeks in 2006 (Baldwin, personal communication, 2006). Available streamflow data are described in greater detail in **Section 5**.

There are approximately 35 reservoirs in WRIA 40A with volumes of 10 acre-feet or greater (smaller private ponds with volumes less than 10-acre feet were not described in this assessment). Eight of these reservoirs are inactive, and all but one were constructed in natural, off-channel basins enlarged to enhance irrigation storage. The Upper Wheeler Reservoir was constructed within the stream channel off Orr Creek. Water levels in these reservoirs are largely sustained by diversions from Squilchuck and Stemilt Creeks and they comprise a total area of approximately 195 acres with storage of approximately 3,500 acre-feet including active and inactive reservoirs (Ecology Dam Safety Office, 2006).

2.3 CLIMATE

The climate in WRIA 40A ranges from semi-arid in the lower elevations to sub-alpine in the higher elevations. Prevailing westerly winds bring moisture across the Cascade Mountains, and higher elevations and west-facing slopes intercept most of the precipitation falling in the watershed. Most precipitation falls as snow above 3,000 feet during the months of October through April (USFS, 1998). Average annual temperatures range from 51.0 degrees Fahrenheit at Pangborn Airport to 40.2 degrees Fahrenheit at Upper Wheeler SNOTEL (**Table 2-2**), (Natural Resource Conservation Service [NRCS], 2006). Temperature and precipitation are discussed in greater detail below.

One climate recording station (the Upper Wheeler SNOTEL station at elevation 4,400 feet) lies within WRIA 40A, and a number are positioned a few miles outside the watershed (**Figure 2-1**, **Table 2-2**). Pangborn Airport, less than 2 miles from the northern boundary of WRIA 40A across the Columbia River, lies at an elevation of 1,279 feet. The inactive Wenatchee station is located 2 miles north and the Wenatchee Experimental Station is 5 miles north of the mouth of Squilchuck Creek. The Grouse Camp SNOTEL is located 5.5 miles west of Naneum Ridge. The Trough SNOTEL is 1.5 miles southeast of the southern tip of WRIA 40A. Two active Snow Course stations are within WRIA 40A and several others are within 10 miles of the watershed. These stations are used to predict snow depths and were not included in the assessment because of their limited use in the study.

Table 2-2. Average Monthly Temperature and Precipitation for Selected Weather Station and SNOTEL sites in the Vicinity of WRIA 40A

Station	Elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Pangborn Airport	1,279													
Mean Temp (F°)		27.9	34.2	43.6	51.5	59.4	66.4	73.3	72.9	63.8	50.9	37.2	28.2	**50.8**
Mean Precip (in)		1.1	0.9	0.7	0.5	0.6	0.6	0.3	0.4	0.4	0.5	1.2	1.4	**8.5**
Wenatchee	~790													
Mean Temp (F°)		29.2	35.1	44.4	52.7	60.9	67.8	74.4	73.7	64.5	52.3	39.1	30.5	**52.1**
Mean Precip (in)		1.4	0.9	0.6	0.5	0.5	0.7	0.3	0.4	0.4	0.5	1.4	1.5	**9.1**
Wenatchee Exp Station	~875													
Mean Temp (F°)		28.6	34.3	43.4	51.0	58.9	65.7	71.74	71.02	61.7	49.6	37.0	28.5	**50.1**
Mean Precip (in)		1.6	1.1	0.8	0.6	0.5	0.7	0.3	0.5	0.5	0.6	1.6	1.8	**10.6**
Grouse Camp SNOTEL	5,380													
Mean Temp (F°)														
Mean Precip (in)		5.2	4.4	3.2	1.9	1.5	1.4	0.7	0.8	0.9	1.6	5	5.9	**32.5**
Trough SNOTEL	5,300													
Mean Temp (F°)														
Mean Precip (in)		4	3.3	2.4	1.6	1.4	1.3	0.8	0.8	1.2	2	4.2	4.1	**27.1**
Upper Wheeler SNOTEL	4,400													
Mean Temp (F°)		24.8	26.4	31.6	37.6	44.9	51.4	58.9	59.5	52.8	40.0	30.2	24.1	**41.6**
Mean Precip (in)		3.8	3.5	2.2	1.7	1.7	1.6	0.7	0.6	1.1	2.1	4.4	4	**27.4**

2.4 PRECIPITATION

Precipitation provides 94 percent of the total water input to the WRIA 40A hydrologic system. Precipitation falling as snow at elevations above 3,000 feet (½ of the basin area) represents 70 percent of total moisture (USFS, 1998). Historic annual precipitation and average monthly precipitation at Pangborn Airport and Upper Wheeler SNOTEL are shown in **Figures 2-3** and **2-4**, respectively.

Methods

Thirty-year average (1971-2000) annual precipitation values from two weather stations were selected to represent low elevation (Pangborn Airport) and high elevation (Upper Wheeler SNOTEL) precipitation within the basin. Average annual precipitation at Pangborn Airport is 8.5 inches and at Upper Wheeler SNOTEL is 27.4 inches (**Table 2-2**). These weather stations are located 10 miles apart and differ in elevation by over 3,000 feet (**Figure 2-5**). Point-data represented by these two weather stations and spatial data from a digital elevation model were used in the Parameter-elevation Regression on Independent Slopes Model (PRISM; Oregon Climate Service [OCS], 2006) to produce a gridded estimate of average annual precipitation throughout the basin (**Figure 2-5**). Dry and wet year conditions were evaluated and defined herein as years having a greater than 25 percent departure from long term average annual precipitation at Pangborn Airport and Upper Wheeler SNOTEL. Because dry and wet conditions do not necessarily occur during the same years at Upper Wheeler SNOTEL and Pangborn Airport, dry and wet year precipitation estimates were made by adding or subtracting 25 percent of average annual precipitation. Cool and warm years were also identified using crop irrigation data for the same period (Smith, written communication, 2006).

Area-weighted averages for annual precipitation during average, dry and wet years were derived from precipitation bands shown in **Figure 2-5.** The precipitation bands were also used to estimate the total volume of water input into the system from precipitation.

Results

The area-weighted, average annual precipitation for WRIA 40A is approximately 21 inches. The Upper Wheeler SNOTEL recorded 5 dry years and 4 wet years during the period of 1982 to 2005. During that same period, Pangborn Airport recorded 7 dry years and 5 wet years. Annual dry-year precipitation is approximately 16 inches and annual wet-year precipitation is 26 inches. The annual volume of precipitation in WRIA 40A is approximately 86,520 acre-feet during an average year, 64,890 acre-feet during a dry year and 108,100 acre-feet during a wet year. **Table 2-3** summarizes precipitation and temperature characteristics for the period from 1982 to 2005.

Table 2-3.
Precipitation and Temperature Characteristics, Pangborn Airport and Upper Wheeler SNOTEL[1]

	Dry Years	**Wet Years**
Pangborn Airport	1985, 1988, 1999, 2000, 2001, 2003, 2005	1983, 1995, 1996, 1998
Upper Wheeler SNOTEL	1985, 1992, 1994, 1999, 2001	1982, 1983, 1984, 1995
	Warm Years[2]	**Cool Years[2]**
WRIA 40A Vicinity	1992, 1994, 1995, 1996, 1998	1982, 1983, 1993

Notes:
1. Dry and wet years were assumed to be years having annual precipitation with greater than 25% departures from average annual precipitation for the period 1982 through 2005

2. Warm and cool years were derived from crop irrigation data for the period 1982 through 2004.
Source: Smith, written communication, 2006

Potential Sources of Error

Other estimates and measurements for average annual precipitation at the headwaters of Mission and Squilchuck Creeks range from 27 to 36.5 inches, which are in line with the Upper Wheeler SNOTEL data. The USFS (1998) reported 28 inches at Mission Creek and Wooldridge (1994) reported 30 inches at upper Squilchuck Creek. In his study of the upper Squilchuck basin, Wooldridge (1994) acknowledged that precipitation could increase with elevation more rapidly than expected uphill from the Upper Wheeler SNOTEL, which might account for greater than anticipated runoff from precipitation estimates. For the period of 1971 through 2000, nearby SNOTEL stations reported 27.1 inches at Trough, 32.5 inches at Grouse Camp and 36.5 inches at Blewett (**Table 2-2**).

The following assumptions were made in the precipitation estimates.

- Average annual precipitation below an elevation of 1,249 feet (Pangborn Airport elevation) is not less than 8.0 inches.
- Maximum and minimum values assigned to each precipitation band produced using PRISM is represented by a single average value.
- Precipitation distribution is primarily controlled by elevation.

In addition this estimate does not consider:

- The influence of micro-climates within the basin;
- Contributions from snow blown into the basin from the Yakima River side of Naneum Ridge by prevailing winds (Wooldridge, 1994);
- Contributions from rime ice derived from fog and clouds that could contribute up to 3-4 inches per year at the highest elevations (USFS, 1969); or
- Seepage of groundwater from outside the boundaries of WRIA 40A, for example, from the face of the cliffs formed by Jumpoff Ridge (Hoselton, 1992).

2.5 TEMPERATURE AND EVAPOTRANSPIRATION

Temperature
Air temperature generally cools with increased elevation at what is known as the wet lapse rate (2.7 F^0 per 1000 feet of increased elevation). Average monthly and annual temperature at selected weather station and SNOTEL sites are summarized in **Table 2-2**. The difference in average annual temperature between Pangborn Memorial Airport and the Upper Wheeler SNOTEL is 9.2 F^0 which corresponds to a lapse rate of 2.9 degrees Fahrenheit per 1,000 feet.

Evapotranspiration
Evapotranspiration (evaporation plus transpiration) accounts for processes that return water on or near the earth's surface back to the atmosphere as water vapor. For the purposes of this study, the term evapotranspiration refers to the return of water to the atmosphere from natural surfaces i.e. soil, rock, and vegetative surfaces, as well as from transpiration from natural vegetation. Evaporation and transpiration resulting from the irrigation of crops is analyzed in the section on irrigation use. Some factors that control evapotranspiration are the type and density of vegetation, air temperature, wind, timing, duration and type of precipitation and slope aspect.

If vegetation has unlimited access to soil water and if the effects of advection and heat storage are ignored, then evapotranspiration will occur at a rate known as potential evapotranspiration (PET). Because soil moisture is often limited in warm and dry climates, PET often exceeds actual evapotranspiration (AET).

Free water evaporation is a term describing the amount of water evaporated from surface water bodies such as lakes, ponds and wetlands. Free water evaporation from major surface water features was estimated in addition to evapotranspiration.

Methods

Average annual PET was estimated using a heat-index method (Thornthwaite, 1948). Average temperature and precipitation from Pangborn Memorial Airport and Upper Wheeler SNOTEL were used to estimate PET at these locations, and an empirical equation (Pike, 1964) relating average precipitation to PET was used to estimate AET. The difference in estimated AET between Pangborn Memorial Airport and Upper Wheeler SNOTEL was distributed among precipitation bands to assign a value for AET to each precipitation band (**Figure 2-5**). The sum of actual evapotranspiration in each precipitation band was used to calculate an area-weighted average value of AET for WRIA 40A. The percent of precipitation lost to evapotranspiration during an average year was applied to estimate the volume of water lost to evapotranspiration during dry and wet years.

Free water evaporation was estimated using evaporation pan data collected at the Wenatchee Experimental Station (elevation ~875 feet) from 1957 to 1997 (OCS, 2006). Evaporation pan data, from recordings taken during the months of April through October, indicate annual pan evaporation is 40.88 inches. This value was multiplied by a pan coefficient of 0.70 to adjust for excess loss caused by heating of the pan and to incorporate differences in elevation between the Wenatchee Experimental Station and higher elevations in WRIA 40A. There are no pan data available within WRIA 40A.

Results

The area-weighted annual average-year evapotranspiration (average annual evapotranspiration) for WRIA 40A is approximately 10.9 inches or 52 percent of average annual precipitation. In dry and wet years, 52-percent of precipitation corresponds to 8.2 and 13.7 inches, respectively. The total annual volume of water leaving the WRIA 40A system through evapotranspiration is 44,900 acre-feet during an average year, 33,740 acre-feet during a dry year and 56,210 acre-feet during a wet year.

AET is limited by available moisture. As precipitation increases, AET approaches PET. Because the warmer and drier Pangborn Airport has a much higher PET than the Upper Wheeler SNOTEL (**Table 2-4**), AET should increase faster with precipitation at Pangborn than at the higher elevations. However, the higher elevations, which experience the most precipitation and cover more of WRIA 40A, likely control average evapotranspiration. Less than 15 percent of the area in WRIA 40A lies at elevations near or less than Pangborn Airport and nearly half of the basin is located above 3,000 feet elevation. Therefore, it is probable that the area-weighted average AET is relatively insensitive to changes in precipitation that lie within the typical range of precipitation in WRIA 40A. This supports applying a constant evapotranspiration rate to estimate AET during dry and wet years.

Annual free water evaporation is estimated to be 28.6 inches. This value, applied to the approximately 195 acres of lakes, ponds and reservoirs in WRIA 40A corresponds to a volume of 465 acre-feet of evaporation per year.

Table 2-4.
Annual Evapotranspiration Estimates for Average, Dry and Wet Years, WRIA 40A

	Elevation (feet)	PET[1] (in/yr)	AET[2]		
			Average Year (in/yr)	Dry Year[3] (in/yr)	Wet Year[3] (in/yr)
Pangborn Airport	1,249	28.1	8.0	3.2	5.3
Upper Wheeler SNOTEL	4,400	13.3	11.9	10.7	17.8
Average Evapotranspiration in WRIA 40A		16.9	10.9	8.2	13.7

Notes:
1. PET = Potential Evapotranspiration: the amount of water lost to evapotranspiration in an average year given unlimited moisture availability.
2. AET = Actual Evapotranspiration: the amount of water actually lost to evapotranspiration, limited by moisture availability. AET during an average year is an area-weighted average. AET during dry and wet years was estimated using the evapotranspiration rate established in the AET estimate for an average year of 52 percent.

Potential Sources of Error

Estimates for evapotranspiration in WRIA 40A are consistent with other published estimates. Average annual AET in areas near WRIA 40A was estimated by the USGS (Bauer and Vaccaro, 1990) at approximately 12 inches or 48 percent of average annual precipitation in upper Naneum Creek (similar to the upper elevations of WRIA 40A), approximately 9 inches or 87 percent of average annual precipitation in the southern half of Douglas County (similar to the middle elevations of WRIA 40A) and 7 inches or 90 percent of average annual precipitation in the Quincy Basin area of western Grant County (similar to the lower elevations of WRIA 40A).

The following assumptions were made in estimating evapotranspiration.

- A linear distribution of precipitation and temperature values between the two recorded weather stations, Pangborn Airport and Upper Wheeler SNOTEL.
- A linear distribution of evapotranspiration between recorded weather stations.
- The evapotranspiration rate during dry and wet years is equal to the rate during an average year.

In addition, this estimate does not consider the influence of wind and micro-climates within the basin.

2.6 GEOLOGY AND GROUNDWATER

Sources of information
Geologic studies have been conducted in the Wenatchee area since the early 1900s. These studies have been compiled and expanded by Gresens et al, (1981), Gresens, (1983) and Tabor et al., (1987). Ecology completed two hydrogeologic studies for the Cortez Lake area (Ecology, 1984) and the Malaga-Stemilt basins (Hoselton, 1992). These sources of information, along with drillers logs compiled by Ecology provide the background for the following summary of hydrogeologic and groundwater characteristics of WRIA 40A. The geologic map by Tabor et al., (1987) was compiled by the Washington State Department of Natural Resources (WADNR) into an electronic format, and was used in this report to illustrate the geologic units exposed at the surface in WRIA 40A on **Figure 2-6**.

2.6.1 Regional Geologic Characteristics

Geologic Units
Several distinct geologic units occur in WRIA 40A that describe a complex geologic history of shallow marine deposition, extensive basalt volcanism, landslides and catastrophic flooding that affect the occurrence of groundwater in the watershed. Large-scale folding and faulting deformed, tilted, and fractured sandstone and volcanic rocks, affecting their ability to store and transmit groundwater. The landslide events created an unusual hummocky terrain with small closed basins that promote infiltration and have been enlarged and enclosed to create water storage facilities. Flood deposits are relatively widespread and contain significant coarse-grained layers that supply the largest quantities of groundwater in the watershed.

The following broadly summarizes the general geologic conditions in the watershed. The sources described above provide detailed descriptions and delineations of individual geologic formations.

Tertiary Sandstone Units
The oldest geologic units exposed at the surface in WRIA 40A consist primarily of mid-Eocene to early Oligocene-age (or possibly Miocene-age) Tertiary sedimentary rocks identified as the Chumstick and Wenatchee Formations[1]. These units are composed of white to brown, fine to coarse-grained sandstone, interbedded with lesser units of conglomerate, siltstone, mudstone and coal. The older Chumstick Formation contains a fine-grained subunit (Nahahum Canyon Member), which generally lies between the Wenatchee and Chumstick Formations.

Tertiary sandstone units are hundreds to more than 1,000 feet thick in WRIA 40A, and occur at the surface primarily in the lower Squilchuck and Pitcher Canyon drainages in the Squilchuck sub-basin. The Tertiary sandstone units are generally covered by younger basalt and landslide units in the Stemilt and Malaga sub-basins, although some landslide units contain blocks of sandstone.

[1] Basement rocks for the watershed consist of metamorphic gneiss and granitic rocks, which are not exposed at the surface (Tabor, et al, 1987).

Tertiary Grande Ronde Basalt
The mid-Miocene-age Grande Ronde Basalt of the Columbia River Basalt Group (CRBG) comprises much of surficial bedrock immediately south and southeast of WRIA 40A. The Grande Ronde Basalt lies on the eastern watershed boundary on Jumpoff Ridge and on the southern boundary along Naneum Ridge. The Grande Ronde Basalt is comprised of the headwaters of Big Stemilt, Middle and Orr Creeks in the Stemilt sub-basin. Elsewhere, Grande Ronde Basalt occurs as small fragments to very large blocks within younger-age landslide deposits.

In general, the Grande Ronde Basalt consists of several hundred to nearly 2,000 feet of columnar, blocky, rubbly, and fractured layers of dark gray to brown weathered lava typical of those exposed in coulees and along the Columbia River in much of central Washington. The Grande Ronde Basalt may contain minor layers of fine-grained sandstone, siltstone and clayey units between layers of basalt lava, which are exposed along the face of Jumpoff Ridge.

*Tertiary to Quaternary Landslide Unit*s
Uplift, tilting, and compression of the crust in the Wenatchee region during late Tertiary (Pliocene) age destabilized the basalt layers overlying sedimentary rocks and led to large scale rock avalanche and land sliding events. Older landslide debris flows filled ancient stream beds and became solidified. These older solidified deposits were more resistant to erosion than underlying sandstone rocks. When the sandstone eroded away, caprock ridges formed along the divides between sub-basins, including the Wenatchee Heights ridge, several ridges above Pitcher Canyon and the ridge above Beehive Reservoir. Younger landslide deposits occur at the surface in much of the Stemilt sub-basin and in the headwater basin of Squilchuck Creek below the summit of Mission Ridge (**Figure 2-6**).

Landslide deposits consist primarily of basalt rubble with occasional blocks and layers of sedimentary rock or unconsolidated sediment. The disordered landslide deposits lack internal structure or orientation and vary widely in lithology, ranging from open, blocky basalt rubble to lithified mudflows of basalt and sandstone in a matrix of silt and clay. The landslide deposits overlie sandstone units, which were likely deeply weathered and eroded before landslide events began. Consequently, the thickness of the landslide deposits varies widely, depending on the pre-slide surface topography, and ranges from tens to hundreds of feet.

Quaternary Glacial Flood Units
Turbulent events continued to substantially modify the terrain of WRIA 40A preceding and during Quaternary age glaciation (approximately 12,000 to 18,000 years ago). Large landslides blocked the Columbia River and formed dams that led to deposition of extensive fine-grained sand and silt layers near Malaga, and scattered and isolated deposits of sand and gravel along slopes above the Squilchuck and Stemilt Creeks. Catastrophic release of water behind ice dams in northern Washington and northern Montana flooded the Columbia Basin, scoured channels down to basalt bedrock and deposited extensive layers of coarse to fine-grained sediment along the scoured channels. These deposits primarily occur within

1 mile of the Columbia River in WRIA 40A, and consist of tens to 100-foot thick layers of sand, silt and gravel.

Recent Alluvial Deposits and Landslide Units
Thin and discontinuous layers of coarse to fine-grained alluvium lie along and beneath all drainage channels in WRIA 40A. The alluvial deposits are no more than 100 feet thick and vary widely in composition from thin silt lenses to thick gravel layers. Steep slopes remain susceptible to release of small to large landslides that discharge onto flat benches or stream channels. Like the much larger, historical landslides, recent slides consist of a jumbled mixture of basalt blocks and sedimentary rock in a matrix of sand, silt and clay.

WRIA 40A HYDROGEOLOGIC CHARACTERISTICS

Sandstone Units
Sandstone units contain little primary porosity to store groundwater within pore spaces of the rock. Openings between layers and along fractures locally create secondary porosity and increase groundwater storage. However, clay or other secondary minerals may seal the openings and decrease permeability. Bedding and fracturing trends are generally oriented northwest to southeast, which locally controls groundwater flow directions and the flow of groundwater to wells completed in these openings.

Depth to groundwater in the sandstone units varies widely, from tens to hundreds of feet. Driller logs typically report layers of light colored sandstone, siltstone and clay that are dry, damp or wet, and sporadically and discontinuously contain groundwater. Groundwater levels in sandstone wells completed deeper than 150 feet typically rise to within 50 to 100 feet of ground surface, indicating confined conditions that pressurize the groundwater within fractures and along bedding planes. Groundwater in the sandstone units is replenished by slow percolation of rainwater through bedding and fractures at the surface or indirectly via recharge through overlying basalt or landslide units. Groundwater withdrawals from domestic wells yield in the range from 1-to-30 gallons per minute (gpm), but are typically less than 10 gpm. Groundwater in the sandstone units generally occurs in isolated, discontinuous, moderately permeable layers or in open fractures that yield small quantities of water to single residence domestic wells. Although groundwater is widespread in the sandstone unit, the amount of available groundwater at any one location is unpredictable.

Grande Ronde Basalt
Grande Ronde Basalt outcrops only on the southern and eastern watershed boundary, and therefore is a minor water-bearing unit in the watershed. The deeply fractured permeable basalt promotes infiltration of precipitation that recharges deeper basalt layers. Groundwater within the basalt units also recharges underlying units along the southern and eastern watershed boundary. Groundwater may also feed seeps and springs at the contact of the basalt units and underlying or adjacent landslide units. Few wells are completed in the Grande Ronde Basalt in WRIA 40A. Ecology well logs report several dry holes and several productive wells drilled in basalt in T21N R21E Sections 4 and 7.

Groundwater, where present in the basalt, likely occurs at depths that exceed one hundred to several hundreds of feet deep, and likely occurs near the base of the basalt unit. Yield to wells ranges from 10 to 100 gpm. Because groundwater in the basalt units is restricted to the margins of the watershed and drilling and groundwater development has been limited, the extent and availability of groundwater in basalt is limited, unpredictable and discontinuous. However, some springs emanating from the base of the basalt units may discharge sufficient groundwater for public supply and irrigation (Laurel Hill Service Association, Stemilt Irrigation District, Tincher-King, and Galler Ditch Company).

Landslide Units

Groundwater occurrence in the landslide units reflects the chaotic history and variable composition of the units. The discontinuous blocks and debris flows contain variable amounts of groundwater that reside within fractures and voids of large landslide blocks, and within pore spaces of granular layers of smaller debris flow. Groundwater in the landslide units is recharged by direct infiltration of rainwater, indirect recharge from adjacent units or by infiltration of irrigation return flow, particularly in the Wenatchee Heights, Stemilt Hill, and Malaga area near Cortez and Meadow Lakes. Depth to water typically ranges from 50 to 150 feet, although many borings encountered no groundwater for several hundred feet. Wells completed in the landslide units may yield more than 100 gpm, particularly when completed in basalt rubble, but typically only support withdrawals of 5 to 30 gpm. The permeability of the landslide units varies widely, and the water-bearing zones may exhibit either unconfined or confined conditions. Groundwater occurrence and availability in the landslide units, like the sandstone units, is variable and unpredictable. However, some well logs indicate a greater potential for higher yields at the base of the landslide deposits where the contact with underlying sandstone may consist of relatively open, porous structures, for example, below Wenatchee Heights and near Cortez Lake. The Three Lakes Water District and Malaga Water District derive some of their water from landslide units.

Glacial Flood Units

Groundwater occurs extensively in the glacial flood units generally at depths less than 100 feet and within moderate to high permeability coarse sand and gravel layers interbedded with very low permeability silt units. The silt layers isolate and impede groundwater flow, whereas high permeability layers yield significant flow to wells in the range of tens to hundreds of gpm. The glacial flood units are recharged by precipitation, lateral discharge from adjacent units and by percolation of return flow from irrigation water and domestic wastewater. The flood units exhibit the highest permeability of any units in the watershed; consequently, these units provide the most significant source of groundwater in WRIA 40A and are tapped for domestic, irrigation, and municipal withdrawals, such as the Malaga Water District and De Chenne Water System and several smaller public (Group B) systems.

Alluvium and Recent Landslide

The limited extent and thickness of the alluvial units also limits the amount of groundwater in the units. Their relatively high permeability, however, likely promotes infiltration of precipitation, which then recharges underlying units or discharges as springs at the base of the units. Yield to domestic wells in the alluvium and recent landslide deposits are expected to range from 10 to 100 gpm, but because of their limited size, are not considered significant sources of groundwater for uses other than single residence domestic supply and a few smaller public (Group B) systems.

Hydrostratigraphic Relationships between the Units

Groundwater exchange between the hydrogeologic units affects groundwater availability and discharge to surface water. This exchange varies widely and depends on the permeability of the contact material, which ranges from rubbly, porous conglomerate and landslide debris, to layers of impermeable clay. For example, permeable broken basalt layers containing significant volumes of groundwater recharge deeper landslide and sandstone units, whereas sandstone underlying low permeability silt and clay-rich layers at the base of landslide deposits receives little recharge from overlying units. No distinct and extensive aquitards or aquifers exist in WRIA 40A. Water-bearing zones within the geologic units exhibit both confined and unconfined conditions and are abruptly bounded by fractures or contacts with other units. All of these variable hydrogeologic and hydrostratigraphic characteristics within each of the geologic units and at their contacts lead to unpredictable occurrence of groundwater, resulting in unpredictable groundwater development for much of the watershed outside of the more uniform flood deposit units.

2.6.2 Hydrologic Cycle of WRIA 40A

Groundwater in the watershed is replenished from precipitation falling in the basin and infiltrating into porous surficial deposits. Hummocky terrain, areas with flat to moderate relief, and areas of relatively fresh outcrops of basalt or landslide units promote groundwater recharge; in contrast, steep, barren terrain, particularly in areas where sandstone bedrock is exposed, promotes runoff. In general, the areas of basalt and landslide deposit outcrop tend to promote recharge, and areas of sandstone bedrock promote runoff. Groundwater is recharged artificially via seepage from unlined irrigation reservoirs and ditches, via return flows from irrigated lands, and via seepage from Cortez and Meadow Lakes in the Malaga sub-basin. Groundwater elevations and yield to wells in these areas are expected to be artificially high relative to non-irrigation conditions.

Precipitation and irrigation return flow that enters the subsurface below the root zone migrates with groundwater along flowpaths of greatest permeability and gradient. The chaotic structure of the landslide deposits and the structural orientation of fractures and bedding locally affect groundwater flow paths, but in general, the steep relief of the watershed controls the groundwater flow directions. Deeper groundwater flows generally parallel to slope, and shallower groundwater flow paths will deflect towards stream channels and away from ridges. The streams in the upper basin are likely "losing streams," that is, surface water tends to seep out of the streams into underlying soil, promoting groundwater recharge. In the lower basins, the streams are likely "gaining," that is, groundwater from geologic units seep into the stream, promoting baseflow. Seepage into streams is likely greater near areas of irrigation water storage, conveyance and application where return flow discharges at the surface.

2.6.3 Groundwater Elevations and Flow

The widely variable conditions that affect groundwater elevations, including seasonal and long-term precipitation trends, topography, subsurface structure, lithology and the lack of groundwater elevation data from existing wells prevent accurate determination of the elevation, flow directions or velocity of groundwater within the watershed. Groundwater withdrawals will locally affect groundwater levels, but not sufficiently to alter local groundwater flow directions, except near the largest municipal wells in the Malaga sub-basin.

The total groundwater flow through the watershed can be estimated by assuming regional characteristics for a single basin-wide aquifer with an average thickness of 100 feet, hydraulic conductivity of 1 foot per day and a width of 6 miles. Assuming that the hydraulic gradient is equal to the regional topographic slope (0.1 ft/ft), the bulk groundwater flow in this theoretical representation would be approximately 2,500 acre-feet per year. This number grossly approximates the volume of groundwater flow in the watershed for comparison to precipitation and surface water runoff.

Hydraulic Boundary between WRIA 40A and Columbia River

Within approximately ½ mile of the Columbia River, the groundwater flow directions and hydraulic gradient of the hydrogeologic units are potentially controlled by the river stage. This effect increases with proximity to the river. The area near Malaga potentially experiences the greatest river influence, where portions of the permeable flood deposits are in hydraulic continuity with the river. The river has little influence on groundwater elevations along the shoreline between the outlets of Squilchuck and Stemilt Creek, where sandstone bedrock slopes steeply into the river. The degree of hydraulic continuity between the river and geologic units, and therefore, the hydraulic boundary of WRIA 40A, is indefinite. This boundary is a significant characteristic of the watershed and could be determined by accurate mapping of groundwater elevations in existing wells. Boundary delineation would support water balance estimates, determining the potential availability of groundwater in the watershed, identifying hydraulic continuity between groundwater and the river to identify areas of sustainable yield, and would be required for establishing impacts of groundwater withdrawal on instream flow. The Columbia River Water Management Program includes a water inventory of the zone within 1 mile of the Columbia River as a potential boundary to indicate influence of the river (Engrossed Second Substitute House Bill 2860).

2.6.4 The Physical Availability of Groundwater in WRIA 40A

Figure 3-4 shows the distribution of domestic, municipal and irrigation wells recorded by Ecology for WRIA 40A. The map illustrates areas of the highest density of groundwater withdrawal, which generally indicates the availability of groundwater in the watershed. Groundwater withdrawal in upland areas generally occurs at exempt wells to supply single residence domestic use. **Figure 2-5** also shows public supply wells and springs and indicates that most higher yield wells derive groundwater from flood units and landslide units in the Malaga area (for example, the Malaga Water District, the Three Lakes Water District and the De Chenne Water System).

Based on the hydrogeologic review and available well records, **Table 2-5** summarizes the groundwater development potential of various regions of the watershed based on typical yield to wells. This summary does not include potential groundwater sources within alluvial units next to and in hydraulic continuity with the Columbia River, which may potentially yield 1,000+ gpm to wells (for example, at the KB Alloys and Alcoa facilities near the farthest eastern boundary of WRIA 40A).

Table 2-5
Groundwater Development Potential in WRIA 40A

Hydrogeologic Unit	Region	Well Yield
Flood Units	Malaga, Three Lakes	10 to 100+ gpm
Alluvium	Lower Stemilt Creek, Lower Squilchuck Creeks	10-100 gpm
Grande Ronde Basalt	Upper Stemilt Creek, Middle Creek, Orr Creek	0 to 100 gpm
Landslide Units (near surface water)	Malaga	0 to 50 gpm
Landslide Units (directly above bedrock)	Stemilt Hill, Wenatchee Heights	0 to 30 gpm
Sandstone Units	Middle Squilchuck Creek (Halvorson Canyon), Pitcher Canyon	0 to 30 gpm

2.7 GROUNDWATER RECHARGE

Precipitation that is not lost to evapotranspiration does not runoff to surface water channels, and infiltrates below the root zone in soil is considered groundwater recharge. Some of the recharge will eventually return to the surface where groundwater tables intersect low-lying land surface (for example, springs along steep slopes within stream channels or below cliffs), and a portion is recovered by wells. However, much of the groundwater migrates down gradient through geologic units to discharge at the lowest elevation in the watershed at the Columbia River.

Recharge is largely controlled by the capacity of earth material (soil type and underlying geologic structures) to absorb and facilitate the downward migration of water. Fine-grained soils derived from siltstone, for example, usually have low permeability and are often associated with slower recharge rates. If the underlying geology is less permeable than overlying soil, then recharge will be controlled by geology.

Method

As it is impossible to directly measure recharge in a watershed, recharge is often estimated after other components of the water balance have been determined. This method works well for basins having streamflow data. Due to the lack of available streamflow data in WRIA 40A, recharge was estimated by establishing upper and lower limit estimates. Available water capacity (also known as available moisture capacity) is the amount of water in soil that is available to be taken up by plants. It describes the volume of water that a soil can hold between the wilting point and field capacity. If the soil is at its available water capacity, then additional water entering the soil is subject to recharge below the root zone. The available water capacity of soils within the watershed was examined to establish an upper limit for recharge in WRIA 40A. An area-weighted average of the annual available water capacity for soils in the Squilchuck and Wenatchee Heights sub-basins was calculated from digital soils data for Chelan County using GIS. The area-weighted average was extrapolated for the entire watershed because most soils in these two sub-basins are similar to those in the Stemilt and Malaga sub-basins. Recharge has been simulated in various parts of eastern Washington by Bauer and Vaccaro (1990) using United States Geological Survey Deep Percolation Model (DPM). They estimated recharge in the Columbia Basin and Waterville Plateau to be about 1 inch per year. Because climate and geology in the lower elevations of WRIA 40A are similar to the Columbia basin, this value was chosen to represent the lower limit for recharge in WRIA 40A. A simple average of the upper and lower limits of recharge was used to establish a value for average annual recharge.

Results

Recharge in WRIA 40A is controlled by soil permeability. Annual recharge in the basin likely ranges from 1 to 14 inches, with an average of 7.5 inches or 35 percent average annual precipitation. Recharge is not limited by underlying geology, which tends to promote infiltration in the upper watershed via subsurface voids, fractures and bedding planes (see **Groundwater Section**). Variations in recharge during dry and wet years were not examined. Drier years will likely result in less recharge and recharge in wetter years will approach the estimated upper limit of 14 inches per year.

Groundwater recharged by precipitation that returns to the surface to augment streamflow is called baseflow. An undetermined portion of estimated recharge contributes to baseflow for Squilchuck and Stemilt Creeks. Estimating the rate and location of groundwater discharge to streams is further complicated by irrigation diversion for out of stream uses and irrigation return flow. However, in the upper elevation areas of the Squilchuck and Stemilt sub-basins, shallow infiltration is high and approaches 100 percent in the vast areas covered by rubble land rocks (Wooldridge, 1994). A portion of this water presumably returns to the surface via springs to feed Squilchuck and Stemilt Creeks.

Potential Sources of Error

Establishing a lower limit for annual recharge of 1 inch is reasonable as recharge can be negligible in places with less than 10 inches of average annual precipitation (Vaccaro, personal communication, 2006). Most of the lower elevation areas in WRIA 40A receive 10 inches or less of rainfall. The method used to establish an upper limit to recharge does not take into account water that goes to runoff and evapotranspiration, two of the largest output components of the water balance. This exclusion likely causes an over-estimation of the upper recharge limit. However, in the upper elevation areas of the Squilchuck and Stemilt sub-basins infiltration approach 100 percent in the numerous regions covered by rubble land rock (Wooldridge, 1994). In their work simulating recharge using DPM, Bauer and Vaccaro (1990) estimated average annual recharge in the adjacent upper Naneum Creek drainage to be nearly 11 inches, or 43 percent of average annual precipitation. Considering that much of WRIA 40A is below the elevation of upper Naneum Creek, and that the westerly-facing Naneum Creek drainage receives about 15 percent more precipitation than the northeasterly-facing WRIA 40A drainages, it is reasonable to estimate recharge in WRIA 40A as a lower percentage of annual precipitation than in Naneum Creek.

The estimate for recharge does not account for baseflow, which is an important component of total stream volume. For example, in Naneum Creek 74 percent of total streamflow derives from baseflow. In the Squilchuck sub-basin, perennial flow is limited to the upper reaches of Squilchuck, Miners Run and Lake Creeks. In the Stemilt sub-basin, the middle and lower reaches of Stemilt Creek may become dry late in the season, a condition that may have preceded development of irrigation systems (Andonaegui, 2001). Nevertheless, some component of the recharge estimate does augment streamflow. Quantifying baseflow using stream gauge data is complicated by surface diversions which generally occur higher in the watershed (above elevation 3,000 feet), where most precipitation and runoff occurs.

The following assumptions were made in estimating recharge.

- Average available water capacity is the same for soils in Stemilt and Malaga sub-basins as in the Squilchuck and Wenatchee Heights sub-basins.
- Estimates by Bauer and Vaccaro for recharge in the Columbia basin and Waterville plateau are close to actual conditions and can be used to represent low-elevation conditions in WRIA 40A.

In addition, this estimate does not consider:

- The effects of most precipitation occurring as snow;
- Timing of snow melt that is sometimes rapid, potentially causing higher runoff; and
- The fraction of recharge that returns to the surface as baseflow in streams.

Section 3 – Existing Water Rights and Claims

3.0 BACKGROUND

In order to understand the implications of the following discussion about water rights and claims in WRIA 40A, it is important to understand the basics of both water rights and claims. The following is an excerpt from documents prepared by the Department of Ecology (http://www.ecy.wa.gov/programs/wr/rights/water-right-home.html).

> The waters of Washington State collectively belong to the public and cannot be owned by any one individual or group. Instead, individuals or groups may be granted rights to use them. A water right is a legal authorization to use a predefined quantity of public water for a designated purpose. This purpose must qualify as a beneficial use. Beneficial use involves the application of a reasonable quantity of water to a non-wasteful use, such as irrigation, domestic water supply, or power generation, to name a few.
>
> State law requires certain users of public waters to receive approval from the state prior to using water - in the form of a water right permit or certificate. Any use of surface water (lakes, ponds, rivers, streams, or springs) which began after the state water code was enacted in 1917 requires a water-right permit or certificate.
>
> Likewise, withdrawals of underground (ground) water from 1945 onward, when the state groundwater code was enacted, require a water right permit or certificate – unless the use is specifically exempt from state permitting requirements. While "exempt" groundwater uses are excused from needing a state permit, they still are considered to be water rights.
>
> In the 1960's, the Washington State legislature realized the need to document water rights established prior to 1917 for surface water and prior to 1945 for groundwater. These water rights are *vested rights*. A vested right is a water right established through beneficial use of water. A water right claim is a statement of beneficial use of water that began prior to 1917 for surface water and prior to 1945 for groundwater. In 1967, the Claims Registration Act was passed to record the amount and location of these vested water rights.
>
> The Claims Registration Act set a specific time window for water users to file their water right claims with the state. Users of exempt ground-water withdrawals were also encouraged to file claims so that they could establish priority dates for their rights. Some users were not required to file a claim, including:
>
> - Individuals served water through a company, district, public or municipal corporation (the water supplier should have filed claims for its users);
> - Persons with a valid Water Right Permit or recorded Certificate;

- Individuals with a water right determined by Court Decree and recorded through issuance of a Certificate of Water Right by Ecology or one of its predecessor agencies;
- Non-consumptive water uses, like boating, swimming, or other recreational and aesthetic uses, with no physical diversion or artificial impoundment of water; or
- Owners of livestock that drink directly from a surface-water source.

The initial statewide opening of the Claims Registry ended June 30, 1974. The legislature has subsequently re-opened the Claims Registry three times. The most recent opening occurred from September 1997 to June 1998. Statewide, there are roughly 169,000 water-right claims on record.

Claims will remain valid until water rights adjudication occurs, whereby the validity of the claims must be proven before a court of law. Adjudication can be initiated by several means, but normally will not occur unless there are significant problems with water availability in an area. During adjudication, claimants are required to prove that water has been in constant beneficial use prior to 1917 for surface water and prior to 1945 for groundwater. Five or more consecutive years of non-use may invalidate a claim.

3.1 SURFACE AND GROUNDWATER RIGHTS AND CLAIMS IN WRIA 40A

Tables 3-1 a-d summarize surface water and groundwater rights and claims in the Stemilt, Squilchuck, Malaga, and Wenatchee Heights sub-basins. Table 3-1 e presents the total rights and claims for the entire WRIA 40A area. These summaries were derived from Ecology's water rights data base and have been confirmed by Ecology staff.

Ecology's GIS database for water right places of use identifies 747 water rights records (including claims) in the WRIA 40A study area. In addition, Ecology records indicate 17 pending water rights applications for new appropriations of water and 32 pending change applications for existing rights (including 26 for which the Report of Exam has been written and 6 new applications on which no action has been taken).

The 747 total records consists of 351 surface water rights, 78 groundwater rights, 22 reservoir rights (allowing storage and beneficial use of water derived surface water or groundwater sources), and 296 water right claims consisting of 134 groundwater claims and 162 surface water claims.

A general note about reservoir rights:
A reservoir permit is required to store water behind any dam or dike which is capable of impounding water to a depth of 10 feet or more at any point, or which will impound a volume of 10 acre-feet or more at normal pool level. Referred to as a "reservoir right" this permit or certificate typically allows the reservoir to be filled once a year during a specified time of year and with a specified volume of water. In most cases, the subsequent use of water from that reservoir requires a secondary water right for the withdrawal and beneficial use of the stored water.

There are 21 existing permits and 145 water rights certificates issued by Ecology or its predecessor agencies. In addition, there are 144 adjudicated certificates which resulted from the surface water right adjudications in the basin in 1926. There are also 92 certificates of change, which are water rights for which some change has been approved. Neither instantaneous (gallons per minute or cubic feet per second) nor annual quantities (acre-feet per year) of water are allowed to be increased through the water right change process and, in some cases, they may be reduced in situations where the full quantities of water have not been historically put to use. Finally, there are 26 pending applications to change existing water rights for which the Reports of Examination have been completed. These rights could be permits, certificates, adjudicated certificates, or claims. These changes are most commonly a change in type of use, place of diversion or withdrawal, the number of points of diversion or withdrawal, and/or place of use.

Water rights records are summarized in **Figure 3-1,** which shows all of the recorded water rights and claims in WRIA 40A and shows the type of point of withdrawal (headworks gravity flow, surface water pump [surface water], wells [groundwater]), other features such as reservoir dams and irrigation dams, and the places of use associated with water rights and claims. The majority of water uses rely on surface water sources. Approximately 12 of these surface water sources are from the Columbia River and represent the importation of water into WRIA 40A. The importation of water is discussed in more detail in **Section 4.2.**

Current Water Use.
Also, note that there are numerous areas where water right places of use and water right claim places of use appear to overlap. This is consistent with the findings described below under the discussion of ground and surface water claims.

Figure 3-2 shows surface and groundwater rights and claims in WRIA 40A.

Figure 3-3 shows surface water rights and claims by type of use, including municipal, domestic, irrigation, industrial and commercial water uses in WRIA 40A.

Figure 3-4 shows groundwater rights and claims in WRIA 40A for the same categories of use.

Note: Ecology's GIS database for water rights includes points of withdrawal (for groundwater) and point of diversion (for surface water) taken from the water rights documents. Recently, Washington State Department of Fish and Wildlife (WDFW) field staff walked Squilchuck and Stemilt Creeks as part of their Fish Passage Barrier Survey (WDFW, 2006). WDFW inspected the Little Stemilt, Big Stemilt, Orr and Middle Creek tributaries of Stemilt Creek. The survey identified fish passage barriers and fish screens on surface water diversions, and the barriers and diversions which were out of compliance with the fisheries codes. Natural barriers, such as waterfalls or narrow stream reaches too small to meet fish-bearing criteria, were established as the upstream limit of the survey, and WDFW did not map the lower mile of Squilchuck Creek because all of the diversions along this reach were screened and in compliance with the regulations. All other diversions were mapped and identified as non-compliant. On Squilchuck Creek above 1 mile, WDFW identified 23 diversions, whereas Ecology's data base lists 69 diversions for the same stretch of the stream.

On Stemilt Creek, WDFW identified 15 diversions, whereas Ecology's data base lists 55 diversions for the same stream reaches.

Several conditions have led to the discrepancies between observed and recorded diversions. Some water diversions have been abandoned. Some of the observed surface water diversion points are transient, relying upon small gas-powered pumps or even tractors with power take-off driven pumps which are not always located in the stream. However, other unidentified factors likely account for the remainder of the discrepancies, and Ecology and WDFW staff would need to compare records and reconcile the differences.

3.1 .1 Groundwater Claims in WRIA 40A

Groundwater uses that began prior to 1945 and for which claims have been submitted may be valid. Ecology's data base includes 134 groundwater claims in WRIA 40A. Groundwater rights have not been adjudicated in WRIA 40A.

Table 3-1a
Water Rights & Claims* in Stemilt Sub-basin

		Number of Records	cubic feet/second (cfs)	gallons/minute (gpm)	acre-feet/year (afy)	Irrigated Acres
Water Right Permits & Certificates						
Ground Water		3	-	1,484.0	910	165
Surface Water		94	1,144.1	-	15,345	13,769
Reservoir Rights		16	3.7	-	2,447	800
	Total Rights	113	1,147.8	1,184.0	18,702	14,734
Claims						
Ground Water		27	-	270.6	474	100
Surface Water		51	402.8	-	2,598	63
	Total Claims	78	402.8	270.6	3,072	63
	Total Records	**191**				

* **Source: Department of Ecology Water Rights Database**

Table 3-1b
Water Rights & Claims* in Squilchuck Sub-basin

		Number of Records	cubic feet/second (cfs)	gallons/minute (gpm)	acre-feet/year (afy)	Irrigated Acres
Water Right Permits & Certificates						
Ground Water		16	-	494.5	270	134
Surface Water		191	49.5	-	1,970	2,758
Reservoir Rights		5	-	-	446	60
	Total Rights	212	49.5	494.5	2,686	2,952
Claims						
Ground Water		46	-	23,453.2	171	113
Surface Water		55	442.4	-	656,364	112
	Total Claims	101	442.4	23,453.2	656,535	225
	Total Records	**313**				

* **Source: Department of Ecology Water Rights Database**

Table 3-1c
Water Rights & Claims* in Malaga Sub-basin

		Number of Records	cubic feet/second (cfs)	gallons/minute (gpm)	acre-feet/year (afy)	Irrigated Acres
Water Right Permits & Certificates						
Ground Water		55	-	15,814.0	386	668
Surface Water		50	22.9	-	1,450	1,064
Reservoir Rights		2	-	-	660	160
	Total Rights	107	22.9	15,814.0	2,496	1,892
Claims						
Ground Water		54	-	64.3	225	367
Surface Water		45	181.9	-	353	439
	Total Claims	99	181.9	64.3	578	806
	Total Records	206				

*__Source: Department of Ecology Water Rights Database__

Table 3-1d
Water Rights & Claims* in Wenatchee Heights Sub-basin

		Number of Records	cubic feet/second (cfs)	gallons/minute (gpm)	acre-feet/year (afy)	Irrigated Acres
Water Right Permits & Certificates						
Ground Water		4	-	195.0	102	26
Surface Water		19	45.2	-	494	211
Reservoir Rights		0	-	-	-	-
	Total Rights	23	45.2	195.0	596	237
Claims						
Ground Water		7	-	1,141.0	77	14
Surface Water		11	835.7	-	417	56
	Total Claims	18	835.7	1,141.0	494	70
	Total Records	41				

*Source: **Department of Ecology Water Rights Database**

Table 3-1e
Water Rights & Claims* in WRIA 40A (Total of all Sub-basins)

		Number of Records	cubic feet/second (cfs)	gallons/minute (gpm)	acre-feet/year (afy)	Irrigated Acres
Water Right Permits & Certificates						
Ground Water		78	-	17,987.5	5,146	992
Surface Water		351	1,258.3	-	19,258	17,585
Reservoir Rights		22	3.7	-	3,253	1,020
	Total Rights	451	1,262.0	17,987.5	27,657	19,597
Claims						
Ground Water		134	-	24,914.1	945	594
Surface Water		162	1,877.7	-	659,733	1,234
	Total Claims	296	1,877.7	24,914.1	660,678	1,828
	Total Records	747				

*__Source: Department of Ecology Water Rights Database__

Of the 134 groundwater claims, 123 include domestic use as the first use listed (63 of these claims are solely for domestic use); 7 claims list the sole purpose of use as irrigation; and 4 claims include other uses or do not specify a use. The 123 claims including domestic use are likely for residences with a relatively small irrigation component, and are essentially wells allowed by the "exempt well" statute which allows use of a well up to 5,000 gallons per day and up to half an acre of non-commercial lawn and garden irrigation without obtaining a water right from the state. (See the discussion of exempt wells below.)

The water balance has attempted to estimate the number of residences that are relying on individual wells for their water supply and has assumed a daily water use of 380 gallons per day per residence. Any additional assignment of water use to the existing claims would likely result in double-counting of most of these uses.

If the Planning Unit desires additional detail on the land and water use associated with water right claims in WRIA 40A, they may wish to consider including a recommendation in the watershed plan for further work to refine these numbers. However, it should be noted that such a detailed analysis is time consuming, would provide detail on what appears to be a relatively minor water use, and would still be uncertain given that adjudication of water rights is the only way to achieve certainty with respect to water right claims. It may be appropriate to address this piecemeal by sub-basin in order of priority.

3.1.2 Surface Water Claims in WRIA 40A

Of the 162 surface water claims, 95 include a domestic component, 29 are for irrigation only, 34 are for stock water only, 1 is for fire protection (for example sprinkling of log piles or wild vegetation) and 3 have no uses specified.

Surface water rights were adjudicated in 1926. A general adjudication is a legal process conducted through a superior court to determine the extent and validity of all the existing water rights within a particular water system. A general adjudication can determine rights to surface water, groundwater, or both. It does not create new water rights, it only confirms existing rights.

Adjudications provide the only legal means for certainty, clarity and surety for water rights holders, the Department of Ecology and others interested in water rights. When the court confirms a water right, that right becomes enforceable against other water users and can be protected from impairment by illegal users or new water rights applications. Adjudicated rights favor senior water rights holders during times of limited water availability. The adjudication process provides Ecology with information necessary for decision-making regarding the impact of granting new rights and proposed changes to existing rights.

The 1917 surface water code established the system of appropriative rights in Washington State, i.e. the system of water rights permits and certificates. However, before 1917, the State also recognized riparian rights. Riparian rights attach only to land bordering a stream or water body. Owner of more distant land cannot obtain riparian rights for their land.

> There is no priority of right between riparian owners. All riparian owners have equal rights with competing interests to be resolved by the Courts. As demand increased, the riparian doctrine was divided into (a) the natural flow theory and (b) the reasonable use theory.
>
> Under the natural flow theory, the riparian owner could divert water for domestic purposes that included family, livestock, and gardening, and otherwise had the right to have the water in the stream or lake kept at is "natural flow" level. Under the reasonable use theory, the use of the stream is limited to what is reasonable, having due regard for the rights of others on the water source. (Pharris, 2002)

A subsequent Washington State Supreme Court decision ruled that riparian rights, not beneficially used by 1932 were invalid. (See Department of Ecology v. Abbott, 103 Wash.2d 686, 694 P.2d 1071 (1985).

The 1926 adjudication examined and validated existing surface water rights including active pre-1917 vested and riparian rights, and active post-1917 State-issued permits or certificates. Except for riparian rights, any post-1917 use of surface water should have applied for a water right permit from the State. Since 1932, all uses of surface water should have applied for a water right permit from the State. If an application was approved, a permit would have been issued and, once the use was perfected, a certificate would have been issued. If the application was denied, no water use should have occurred.

If a vested right or a riparian right was found to exist in the adjudication, an adjudicated certificate of water right would have been issued. Any rights issued by the State subsequent to 1917 and found to be still valid would also have been issued an adjudicated certificate of water right. Therefore, any current surface water claim for a right other than a riparian right is likely invalid because it was filed for a use that began after the 1926 adjudication and should have had a water right associated with it.

In some cases, people misunderstood the water right claims process and filed claims for uses for which they already have a water right. In such cases, the right is still valid (assuming water is still being used, etc.) and the claim is redundant. For these reasons, the surface water claims are not being specifically factored into the water balance analysis for WRIA 40A.

A general note about the analysis of water right claims.
The data on water right claims was provided by the claimant. In many cases, that person was not well-acquainted with water resources management or water law and, as a result, much of the information on the claims is not accurate. This is especially true where the claimed instantaneous and annual quantities of water are listed. For example, the total number of acres claimed for irrigation in WRIA 40A is 1,234 acres. The total volume of claimed water is 659,733 acre-feet, or 534.5 acre feet of water per acre. Actual water use is more likely to be 2-4 acre-feet of water per acre. Therefore, the claims in the claims register may or may not represent a valid vested water right. However, if they do, the quantities of water listed on the claim are often inaccurate and should not be relied upon for any work related to the water balance for a given area.

3.2 EXEMPT WELLS AND WELL LOGS IN WRIA 40

There are four types of groundwater uses exempt from the state water-right permitting requirements.

- Providing water for livestock (no volume or acreage restriction).
- Watering a non-commercial lawn or garden one-half acre in size or less (no volume limit).
- Providing water for a single home or groups of homes (limited to 5,000 gallons per day).
- Providing water for industrial purposes, including irrigation (limited to 5,000 gallons per day with no acre limit).

These uses are exempt from permitting and establish a water right by putting water to a beneficial use. The priority date for such rights is the date the water was first put to use. In the event of an adjudication of groundwater, any uses that meet the exemption criteria above and for which use can be documented with pumping and drilling records, receipts, etc., would be granted an adjudicated groundwater right for the quantity of water actually put to beneficial use, not to exceed the 5,000 gallon per day limit where it applies. (See RCW 90.44.050). Note that, during adjudication, claimants are required to prove that water has been in constant beneficial use prior to 1917 for surface water and prior to 1945 for groundwater. Five or more consecutive years of non-use may invalidate a claim.

As noted in the discussion of groundwater claims, most of the claims (123 of 134) include domestic as one of the stated water uses. It is very likely that a large number of the claims were filed on wells that are exempt from permitting. Claims for groundwater from wells drilled before 1945, which are still active, may be valid. The practical reality, however, is that a claim for domestic use is inconsequential because such wells are considered a legal source of water upon the date of first use and are only exempt from the permitting process. The only difference would be that pre-1945 wells, with valid claims, would be found to have a 1926 date of priority, which is significant only when periods of water shortage lead to regulation based on seniority (first-in-time, first-in-right). While interruptible rights are regulated fairly often, the regulation of domestic water rights has rarely, if ever, occurred.

Review of well logs reported for WRIA 40A to Ecology was part of the technical assessment work. Well logs submitted by well drillers contain limited to extensive information, including location (often to the nearest ¼, ¼ section), boring and casing diameter, well depth, well construction and testing details (casing type, screen type, pump elevation, yield, drawdown, etc.) and geologic materials encountered at different depths. Ecology's database contains approximately 200 well logs for WRIA 40A. Submittal of well logs before 1971 was voluntary. In 1992, well drillers were required to submit notices of intent to construct a water well (also called "start cards") and Ecology's monitoring increased. As a result, the database is quite complete for wells drilled since 1992, incomplete for the period from 1971-1992, and scattered for pre-1971. It is estimated that the well log data base includes about 70 percent of the wells drilled prior to 1991 (Szymarek, personal communication, 2006).

Section 4 – Estimated Current Water Use

4.0 DRINKING WATER SOURCES AND DOMESTIC WATER USE

Washington State Department of Health (DOH) defines Group A public water systems as those regularly serving 15 or more residential connections, or 25 or more people for 60 days during the year. Group B public water systems provide community supply to 2 to 14 connections having fewer than 25 people. These water systems are subject to state and local ordinances governing water quality and system operations. The DOH is the primary agency for water system regulation and Ecology is the primary agency for water rights regulation. Exempt wells are generally not subject to regulation by DOH or Ecology.

Method

The number of connections and the population served by Group A and Group B public water systems were estimated from information obtained through the DOH website, Hammond, Collier, Wade, Livingstone (Reigert, 2003) and the Malaga Water District (Gardner, personal communication, 2006). The total number of residences in the watershed in 2006 was 1,549 (**Section 6**). The total number of residences was estimated from current population, which is discussed in the context of estimating future population in **Section 6**. Total water use equals the total number of connections listed for each water system in the DOH water system data (minus inactive and multiple sources serving the same system) plus domestic use supplied by exempt wells and other sources. A number of residences in WRIA 40A are served by the Regional Water System, the Group A water system supplying much of metropolitan Wenatchee and East Wenatchee, and sourced by groundwater outside WRIA 40A that is in hydraulic continuity with the Columbia River. Reigert (2003) estimated the number of connections using this imported source, which was adjusted in this report using an annual growth rate of 1.24 percent (see **Section 6**). Residences served by imported water were calculated separately. The number of exempt wells was estimated by subtracting the total number of connections served by Group A and B public water systems (including imported water) from the total number of residences in WRIA 40A.

Approximately 76 percent of households receive water from WRIA 40A groundwater sources; 20 percent of domestic supply depends on imported water, and 4 of domestic use derives from WRIA 40A surface water (**Table 4-1**).

Table 4-1.
Domestic Water Sources in WRIA 40A

	Residences	Total Use acre-feet/year (afy)	Percent of Total Residences
Groundwater[1]	1,178	501	76
Surface Water[1]	59	25	4
Imported Water[2]	312	133	20
Total	**1,549**	**659**	**100**

Notes:
1. Water sources originating within the boundary of WRIA 40A
2. Regional Water System service provided by Chelan County PUD and one residence served by surface water imported from outside WRIA 40A

To estimate domestic water use, a consumption rate of 380 gallons per day (gpd) was assumed for each household. Most residences are occupied full-time. Therefore, the consumption rate was multiplied by 365 days to estimate average annual use by a single household. Local data indicating the amount of water consumed by indoor uses were not available. However, the Water System Design Manual (DOH, 2001) indicates that in Washington State, average domestic water use rarely drops below 200 gpd regardless of rainfall. Therefore, an indoor consumptive rate of 200 gpd was chosen for this estimate. Average outdoor use is estimated to be the difference of the consumption rate for each household and the indoor consumptive rate, or 180 gpd.

Results

Estimates for the number of connections and populations served by Group A and B water systems, exempt wells and imported water (Regional Water System) are shown in **Table 4-2**. Based on the population estimate in **Section 6**, Group A water systems supply 45 percent, exempt wells supply 30 percent, imported water (Regional Water System) supplies 20%, Group B water systems supply 4 percent, and other sources supply 1 percent. The distribution of potable water systems is shown on **Figure 4-1**.

Table 4-2.
Domestic Water Use in WRIA 40A[1]

	Residences	Total Use acre-feet/year (afy)	Indoor (afy)[4]	Outdoor (afy)[5]
Group A[2]	722	307	162	146
Group B	39	17	9	8
Imported Water (Group A)[3]	311	132	70	63
Exempt Wells	472	201	106	95
Other Sources[6]	5	2	1	1
Total number of residences	**1,549**	**659**	**347**	**312**

Notes:
1. Assumes zero system loss.
2. Does not include residences served by Regional Water System (Group A).
3. Imported water serves as an additional input to the water balance.
4. Indoor use is considered return via infiltration from on-site sewage systems.
5. Outdoor use is considered loss via evapotranspiration.
6. Includes 4 residences using surface water sources and 1 residence using imported surface water.

Essentially all indoor water use is treated and disposed via on-site sewage system (OSS); therefore, much of the domestic water returns to the watershed and is a component to the water balance. In contrast, most water for domestic outdoor use is applied as irrigation and is lost through evapotranspiration. Imported domestic water (Regional Water System) that is used for indoor purposes is added to the water balance via return flow from on-site sewage systems.

Potential Sources of Error

The number of residences depending on exempt wells for supply (472 residences) was estimated by subtracting the number of residents served by Group A and B systems, the total number of residences using imported water, and the number of certificated/permitted wells (32 wells) from the total number of residents.

The 184 well borings (many of which were dry holes) reported in Ecology's database and not attached to a certified or permitted right, is significantly lower than the 471 residences potentially relying upon exempt well water sources. Several reasons for the difference between the number of reported wells and the potential number of exempt wells include the following.

- Ecology did not require exempt well reporting before 1971, and did not enforce well reporting until 1992. Ecology estimates that 30 percent of wells drilled before 1992 were not reported (Szymarek, personal communication, 2006).
- Up to six residences can be served by a single exempt well.
- Some households receive domestic water from springs.
- A few residences may haul water for supply.
- Estimated number of households might not reflect actual conditions.

Another potential source of error in the domestic use calculation includes those supply wells that may derive a portion of groundwater withdrawal from recharge through aquifers in hydraulic continuity with the Columbia River. This potential undocumented importation of water into the watershed is likely restricted to wells completed within flood deposits or alluvial aquifers within ½ mile of the river.

The daily consumption rate of 380 gpd that was chosen for this estimate is close to recorded rates from local water purveyors. For example, average daily demand for Malaga Water District is 357 gpd (RH2 Engineering, 2003). Additionally, a daily consumption rate of 380 gpd was used for watershed planning in the adjacent WRIA 45 that has similar climatic conditions (Chelan County, 2006).

The following assumptions were made in estimating domestic water use.

- All domestic irrigation water is lost to the atmosphere.
- All domestic potable water returns as groundwater recharge.

4.1 INDUSTRIAL AND COMMERCIAL WATER USE

Major industrial and commercial water users were identified by examining existing water system information, including engineering reports (Reigert, 2003; RH2 Engineering, 2004) and DOH records (DOH, 2006). Industrial and commercial water users and water use are summarized in **Tables 4-3** and **4-4**. Industrial and commercial water use was estimated by examining use at three facilities that represent the largest industrial and commercial water users in WRIA 40A. Water used for industrial purposes at the KB Alloys facility derives from on-site groundwater sources that may receive some recharge from an aquifer in hydraulic continuity with the Columbia River. KB Alloys discharges its wastewater to the Columbia River via a permitted outfall. Much of the water used for fruit processing at the Stemilt packing plant and for recreation (potable uses) at the Mission Ridge Ski Area likely infiltrates into the ground via on-site sewage systems. However, given the difficulty in estimating the amount of water returned via infiltration and the relatively small component of the water balance, all industrial and commercial water use was assumed to comprise a loss to the WRIA 40A water balance.

Table 4-3.
Numbers of Industrial and Commercial Water Users

District[1]	Industrial	Commercial	Source
MWD	1		RH2, 2004
CPUD	3	1	Reigert, 2003
Mission Ridge PWS		1	Reigert, 2003
KB Alloys	1		WDOH, 2006
Total	**5**	**2**	

Notes:
1. MWD = Malaga Water District, CPUD = Chelan County PUD (Regional Water System)

Table 4-4.
Industrial and Commercial Water Use[1]

Name of Facility	Average Rate gallons/day (gpd)	Total Use acre-feet/year (afy)
Stemilt Packing Plant[2]	18,240	10
Mission Ridge Ski Area[3]	20,000	6
KB Alloys[4]	220,000	247
	Total	**262**

Notes:
1. The three facilities listed are assumed to represent most of the industrial and commercial water use in WRIA 40A.

2. Packing plant operates for several months during the year, total use is from Malaga Water District records (RH2 Engineering, 2004)

3. Use at Mission Ridge Ski Area is based on 90 days of operation during the year.

4. Water is discharged via outfall to Columbia River

4.2 IRRIGATION WATER USE

Method

The area covered by crops within the boundary of WRIA 40A was estimated using a recent color air photo (USDA, 2005) and a GIS. This method combined row crops and tree crops (cherry, apple, pear and vineyard) into total irrigated lands. When possible, grass or alfalfa crop was traced separately. Irrigation requirement data for cherry orchards during 1982 to 2004 (Smith, written communication, 2006) were examined for an average year, warm years, and cool years at 80 percent sprinkler head efficiency (**Table 4-5**). The review period of 1982 through 2004 was selected because it coincides with the period of record for the Upper Wheeler SNOTEL.

Table 4-5.
Irrigation Requirements for Cherry Crop[1]

	Irrigation Requirement		**Actual Use at 80% Efficiency**	
	in/yr	afy	in/yr	afy
Average Year	36	16,420	43	19,430
Warm Year	39	17,790	47	21,410
Cool Year	31	14,140	37	16,970

Source: Smith, personal communication, 2006
Notes:
1. Based on data collected from 1982-2004 for cherry crop at elevations similar to the Columbia River. Values are rounded to the nearest inch.

Table 4-6. Imported Irrigation Water

District	**Source**	**Volume (afy)**
Lockwood-Canady Irrigation District	Columbia River	600
Lower Squilchuck Irrigation District	Columbia River	unknown
Lower Stemilt Irrigation District	Columbia River	2,500
Starr Ranch Growers	Mission Creek	88
Stemilt Irrigation District	Columbia River	2,000
Wenatchee Heights Reclamation District	Columbia River	270

Results

Irrigation water used in WRIA 40A derives primarily from surface water runoff from within WRIA 40A (approximately 72 percent) and partially from imported sources (approximately 28 percent);(**Table 4-6**). A minor amount of irrigation water derives from groundwater (less than 1 percent). The actual quantities of irrigation water from each source are not documented. This assessment assumes that all imported surface water (5,460 acre-feet; see **Section 5**) is used for irrigation, and that the remainder derives from within the watershed (13,970 acre-feet) during an average year.

Total crop cover in WRIA 40A is estimated to be 5,470 acres including 5,290 acres of row or tree crop and 183 acres (3 percent of total) of grass or alfalfa (**Figure 4-2**). Irrigation and storage conveyance systems are shown on **Figure 4-3**. Using the estimates for actual use in **Table 4-5** and a crop area of 5,470 acres, irrigation use in WRIA 40A is approximately 19,430 acre-feet during an average year, 21,410 acre-feet during a warm year and 16,970 acre-feet during a cool year. Most sprinkler inefficiency in tree crops results in over application of water that is largely caused by tree trunks blocking spray patterns. Of the excess water that is applied to a crop, approximately 5 percent to 8 percent is lost to evaporation (Smith, personal communication, 2006). Assuming that up to 92 percent of water "lost" due to sprinkler head inefficiency actually infiltrates below the root zone of the crop, the volume of irrigation water that is returned as groundwater recharge comprises about 15 percent of actual use: 2,980 acre-feet during an average year; 3,280 acre-feet during a warm year; and 2,600 acre-feet during a cool year.

Potential Sources of Error

Several assumptions that could affect accuracy include:

- Cherry is assumed to be the dominant crop and all crops in the watershed were assumed to have the same irrigation requirement as cherry. However, the Stemilt Irrigation District reports irrigated lands for cherry (69 percent), apple (28 percent), and pear (4 percent); (Reigert, 2003). Given the relatively high irrigation requirement of cherry that extends beyond the growing season (Smith, personal communication, 2006), this assumption could lead to an overestimation of irrigation use.
- Standard tree crop sprinkler heads are estimated to be 70-75 percent efficient while newer micro sprinkler heads are estimated to be 80-85 percent efficient (Smith, personal communication, 2006). Because data are not available to determine the number of acres irrigated by standard and micro sprinkler heads, an average sprinkler head efficiency of 80 percent was assumed.
- The irrigation requirement data displayed in **Table 4-5** was collected at elevations close to that of the Columbia River and do not account for the lower irrigation requirement of crops at higher elevations. Use of lower elevation data could cause irrigation use to be over estimated.

Section 5 – Water Balance

A water balance was conducted to increase understanding of the hydrologic system in WRIA 40A. A water balance accounts for inputs, outputs and returns to the hydrologic system. By definition, once all components have been quantified, the water balance should be zero. However, in practice, it is impossible to measure and account for all components of the water balance even in well-instrumented basins having numerous data. Therefore, this approach is intended to compare the relative importance of each water balance component. Although a water balance attempts to account for water input, outputs and returns during a particular year, it does not consider the cumulative effects of previous years. The climatic and water use conditions of the past several years will affect the outcome of a water balance for any given year.

Figure 5-1 schematically illustrates the components and relationships of a water balance.

5.0 METHODS

Typical water balance approaches examine input and output components to the hydrologic system by primarily analyzing precipitation (input) and streamflow data (output). Precipitation and streamflow comprise two significant components of the water balance and data recording these components are relatively common for larger watersheds. However, the absence of streamflow data in WRIA 40A forced the calculation of streamflow (runoff plus baseflow) by estimating other water balance components from existing data and empirical methods. These components include: 1) water input - precipitation and imported surface and groundwater; 2) water output - evapotranspiration, deep recharge, domestic and crop irrigation and industrial use; and 3) water returns - infiltration of excess irrigation and on-site sewage systems that recharge groundwater and partially discharge to streams. The remaining balance was designated runoff, which includes groundwater discharge to streams (baseflow).

A water balance was calculated for natural conditions (without irrigation diversion) during an average precipitation year, and for average, dry/warm, and wet/cool years under developed (with irrigation diversion) conditions. The water balance for dry/warm (worst-case) and wet/cool (best-case) years examines the potential range of water availability and demand. A dry/warm year represents climatic conditions having below-average precipitation and above-average temperatures, and a wet/cool year represents climatic conditions with above-average precipitation and below-average temperatures. The evapotranspiration rate used is equal to the rate estimated for an average year of 52 percent of precipitation. The recharge rate was kept constant for all estimates. Water demand during warm and cool years was adjusted by examining changes to irrigation demand only. Warm and cool year estimates do not account for changes to domestic and industrial/commercial water use that are probably less sensitive to changes in temperature. A water balance for an average year under predicted future conditions is discussed in Section 6.

5.1 RESULTS

5.1.1 Runoff

Runoff was determined from the balance of all other input and output components. Squilchuck and Stemilt Creeks were assumed to convey the majority of runoff. Under natural conditions (without irrigation use or imported water; **Table 4-6**) during an average year, combined runoff for both creeks is estimated at 15 cubic feet per second (**Table 5-1)**. Because the water balance was conducted for the entire management area, streamflow is estimated for the outlets of Squilchuck and Stemilt Creeks, although a portion of runoff would flow within small channels and as overland flow within the Malaga and Wenatchee Heights sub-basins. Both creeks are known to have stretches that occasionally go dry late in the season. Stemilt Creek was reportedly periodically dry even before development of the basin (Andonaegui, 2001).

Under developed conditions, irrigation diversion places a considerable demand on the runoff component of the water balance. The water balance predicts nearly zero runoff during an average year (**Table 5-2**), a negative value during a dry/warm year (**Table 5-3**) and a runoff of 16 cubic feet per second during a wet/cool year (**Table 5-4**). The contribution to streamflow from baseflow by groundwater and irrigation return flow is not quantifiable without accurate streamflow data, and therefore, not estimated. Baseflow contributes to streamflow late into the season in most years.

5.2 WATER BALANCE DISCUSSION

Under natural conditions during an average year, approximately 10,930 acre-feet of runoff, plus any unaccounted baseflow, would be available for diversion to out of stream uses (**Table 5-1**). Estimated irrigation use of 19,430 afy under current conditions (**Table 5-2**) less imported surface water of 5,460 afy under current conditions (**Table 5-2**) exceeds runoff estimates for natural conditions. This disparity highlights the need for accurate streamflow measurements and estimation of baseflow, but also indicates that most or all stream runoff is appropriated for irrigation use.

Although estimated runoff during an average year is approximately zero, and negative during a dry year, streamflow is observed in Squilchuck and Stemilt Creeks during the late season even in dry years. This discrepancy appears because runoff was estimated without using streamflow data to calibrate the water budget. As a result, several sources contributing to streamflow were not taken into account because they cannot be directly measured or because data were not available. Several sources for this flow include:

- The portion of natural groundwater recharge that returns to the surface as baseflow;
- Infiltration of irrigation water from application inefficiency and leaks from storage and conveyance facilities that discharges to streams;
- Non-diverted irrigation water left in the streams;
- Intentional dewatering of irrigation storage facilities as part of normal operations; and
- The water balance represents a "snap shot" of simulated conditions in the watershed. Under actual conditions, upland recharge from wet years may take several seasons to reach stream channels and may ultimately discharge to streams during dry years.

A detailed discussion of the discrepancy between estimated and observed runoff is contained **Section 5.3, Potential Sources Underestimating Runoff**.

During dry/warm years, imported water makes up a larger portion of the water balance than in normal years (**Table 5-3**). As irrigation demand increases, infiltration of excess water also increases. This exemplifies how watershed conditions in the basin respond differently to changes in climatic conditions and water use. During wet/cool years, estimated surplus runoff is about 11,800 acre-feet (**Table 5-4**). However, the downstream conveyance of some of this surplus water will likely be delayed as recharge rates increase during wet years. Although not reflected in the water balance, increased precipitation will facilitate greater infiltration and recharge. Recharge may approach the estimated upper limit of 14 inches per year. Some of this recharge will be released slowly from the ground to augment streams over several months and possibly several years, potentially dampening the effects of subsequent dry years.

Precipitation, evapotranspiration, and recharge are sufficiently large variables in the water balance that even small changes (or errors) in their estimated quantity can dramatically change estimates for runoff. Estimated runoff is about 12,000 acre-feet lower or higher during a dry or wet year, respectively, than during an average year (**Tables 5-2, 5-3, 5-4**). This difference is caused by a change in precipitation of only 25 percent. Aside from being a source of error (see the error discussion, below), this illustrates how runoff might be affected by relatively small changes to climate or to land cover. For example, a massive forest fire in the upper elevations might substantially increase streamflow and peak flow timing, causing problems of flooding, erosion, and sedimentation. This sensitivity to precipitation also illustrates both the opportunities to capture surplus runoff and the necessity to efficiently manage available water in drier years.

Table 5-1
Water Balance - Natural Conditions[1], Average Year

Input	**acre-feet**	**inches**	**Percent of Precipitation**	
Precipitation	86,520	21.0	100	
Output				
Evapotranspiration	44,900	10.9	52	
Recharge	30,690	7.5	35	
Runoff		*see below*		
Subtotal	75,590	18.4	87	
Return				
Baseflow	unknown	unknown	unknown	
				Flow (cfs)[2]
Balance (runoff)	10,930	2.6	13	15

Notes:
1. Components of the water balance were estimated using existing data. Because there are no continuous streamflow data available, runoff was estimated to be the balance after all other components were estimated.

2. Runoff is estimated average annual combined flow for Squilchuck and Stemilt creeks.

Table 5-2.
Water Balance - Existing Conditions[1], Average Year

Input	**acre-feet**	**inches**	**Percent of Precipitation**	
Precipitation	86,520	21.0	100	
Surface Water Import	5,460	1.3	6.3	
Groundwater Import	130	<0.1	0.2	
Subtotal	92,110	22.4	106.5	
Output				
Evapotranspiration	44,900	10.9	51.9	
Recharge	30,690	7.5	35.5	
Runoff		*see below*		
Domestic Irrigation	310	0.1	0.4	
Crop Irrigation	19,430	4.7	22.5	
Free Water Evaporation	470	0.1	0.5	
Industrial Use	260	0.1	0.3	
Subtotal	96,060	23.4	111.1	
Return				
Septic	420	0.1	0.5	
Irrigation Infiltration	2,980	0.7	3.4	
Subtotal	3,400	0.8	3.9	
				Flow (cfs)[2]
Balance (runoff)	-550	-	-0.7	-1

Notes:
1. Components of the water balance were estimated using existing data. Because there are no continuous streamflow data available, runoff was estimated to be the balance after all other components were estimated.

2. Runoff is estimated average annual combined flow for Squilchuck and Stemilt creeks.

Table 5-3
Water Balance - Existing Conditions[1], Dry/Warm Year

Input	**acre-feet**	**inches**	**Percent of Precipitation**	
Precipitation	64,890	15.8	100	
Surface Water Import	5,460	1.3	8.4	
Groundwater Import	130	<0.1	0.2	
Subtotal	**70,480**	**17.1**	**108.6**	
Output				
Evapotranspiration	33,740	8.2	52.0	
Recharge	30,690	7.5	47.3	
Runoff		*see below*		
Domestic Irrigation	310	0.1	0.5	
Crop Irrigation	21,410	5.2	33.0	
Free Water Evaporation	470	0.1	0.5	
Industrial Use	260	0.1	0.4	
Subtotal	**86,880**	**21.2**	**133.7**	
Return				
Septic	420	0.6	0.6	
Irrigation Infiltration	3,280	0.8	5.1	
Subtotal	**3,700**	**1.4**	**5.7**	
				Flow (cfs)[2]
Balance (runoff)	-12,690	-2.7	-19.4	-17

Notes:
1. Components of the water balance were estimated using existing data. Because there are no continuous streamflow data available, runoff was estimated to be the balance after all other components were estimated.

2. Runoff is estimated average annual combined flow for Squilchuck and Stemilt creeks.

Table 5-4
Water Balance - Existing Conditions[1], Wet/Cool Year

Input	acre-feet	inches	Percent of Precipitation	
Precipitation	108,100	26.3	100	
Surface Water Import	5,460	1.3	5.0	
Groundwater Import	130	<0.1	0.1	
subtotal	113,690	27.6	105.1	
Output				
Evapotranspiration	56,210	13.7	52.0	
Recharge	30,690	7.5	28.4	
Runoff		*see below*		
Domestic Irrigation	310	0.1	0.3	
Crop Irrigation	16,970	4.1	15.7	
Free Water Evaporation	470	0.1	0.5	
Industrial Use	260	0.1	0.2	
subtotal	104,910	25.5	97.1	
Return				
Septic	420	0.1	0.4	
Irrigation Infiltration	2,600	0.6	2.4	
subtotal	3,020	0.7	2.8	
				Flow (cfs)[2]
Balance (runoff)	11,800	3.0	10.8	16

Notes:
1. Components of the water balance were estimated using existing data. Because there are no continuous streamflow data available, runoff was estimated to be the balance after all other components were estimated.

2. Runoff is estimated average annual combined flow for Squilchuck and Stemilt creeks.

5.3 POTENTIAL SOURCES OF ERROR

Assuming the combined average flow in Squilchuck and Stemilt Creeks under natural (non-irrigation) conditions is apportioned equally, each stream would have an average flow of 7.5 cubic feet per second. This estimate is consistent with the limited existing measured streamflow data **(Table 5-5)**.

Average annual streamflow in upper Squilchuck Creek (above the confluence of Lake and Squilchuck creeks) is estimated by USFS (1998) (using data from Wooldridge (1972) and the Pacific Northwest River Basin Commission (1970) to be 3.0 cubic feet per second. Wooldridge (1994) used the same data to estimate average flow in upper Squilchuck Creek above the Beehive Reservoir intake to be 2.0 cubic feet per second. Although the basin areas that correspond to these average flow estimates are relatively small (from 1 to 3 square miles) they represent some of the highest precipitation levels in WRIA 40A. The contribution to streamflow from the highest elevations is proportionally greater than for lower areas. Nearly half of WRIA 40A is located above 3,000 feet elevation.

In another study, flow in Squilchuck Creek was measured for approximately one year by the Chelan County Conservation District (CCCD, 1990) below the State Park. Results of this work as it appears in USFS (1998) are unclear. Data from CCCD were not available.

Table 5-5. Existing Measured Stream Flow in WRIA 40A[1]

Date	Squilchuck (cfs)	Stemilt (cfs)	Location	Source
9/9/1926	1.7	-	SW 1/4 21-20-4	Ruppert, written comm.
9/23/1926	1.8	-	SW 1/4 21-20-4	Ruppert, written comm.
9/11/1967	3.5	-	SW 1/4 21-20-5	Ruppert, written comm.
9/15/1970	2.5	-	County Rd xing 22-20-33	Ruppert, written comm.
2/28/1977	2.23	-	near mouth	Ruppert, written comm.
8/25/1977	0.01	-	near mouth	Ruppert, written comm.
4/3/1987	5.6	4.3	near mouth	Clausing, 1984
5/11/1987	13.1	22.9	near mouth	Clausing, 1984
6/8/1987	5.3	2.2	near mouth	Clausing, 1984
7/22/1987	4.9	5.7	near mouth	Clausing, 1984
10/5/1987	1.2	0.3	near mouth	Clausing, 1984
Oct- 1992[2]	1.8	-	upper Squilchuck	Wooldridge, 1994
May-1993[2]	15.1	-	upper Squilchuck	Wooldridge, 1994
Aug- 1993[2]	5.0	-	upper Squilchuck	Wooldridge, 1994
3/16/2006	3.7	-	near mouth	Baldwin, pers. comm.
3/22/2006	-	1.7	near mouth	Baldwin, pers. comm..
5/16/2006	18.9	10.5	near mouth	Baldwin, pers. comm.
Average Annual Flow	2.0	-	upper Squilchuck	Wooldridge, 1994

Notes:
1. These are existing available stream flow data. Other efforts to record streamflow in WRIA 40A include Chelan County Conservation District (1990);(Squilchuck Creek) and additional monitoring of upper Squilchuck Creek by Wooldridge.

2. Estimated average for month

Potential Sources Overestimating Runoff

Because the water balance was conducted for the entire management area, estimated streamflow is assumed to be at the mouths of Squilchuck and Stemilt creeks. Observed streamflow at these locations may be less than predicted as a portion of runoff from WRIA 40A will discharge directly into the Columbia River via smaller intermittent channels. The runoff estimate adds water to the Squilchuck and Stemilt sub-basins that might otherwise runoff from the Malaga and Wenatchee Heights sub-basins, although this volume is assumed to be small. According to USFS (1998), elevations below 1,500 feet do not produce streamflow except for during times of snowmelt or thunder storms.

Potential Sources Underestimating Runoff

Despite water balance estimates for runoff that predict near zero flow under some existing conditions, water rarely ceases to flow in Squilchuck and Stemilt Creeks. This discrepancy exists because of potential error in the water balance estimate (primarily evapotranspiration and recharge components) and also because baseflow was not estimated. It is not possible to measure these major components of the water balance, so they must be estimated from existing data using empirically derived methods. Because they are significant elements of the water balance, errors in their estimation will directly affect the estimation of runoff and consequently, estimates of water availability. For example, reducing the recharge or evapotranspiration rates by 10 percent would add 3,000 to 4,500 afy to runoff estimates, respectively. For any component of the water balance, error that is less than 10 percent is considered satisfactory. Another likely cause of underestimating runoff is that baseflow was not accounted in the water budget. Baseflow is water initially lost to recharge, that returns to the surface to augment streamflow. Without actual stream gauging data, all water going to recharge was conservatively assumed to be lost from the hydrologic system. However, in many watersheds, baseflow makes up an important component of streamflow. Additionally, water is maintained in streams from irrigation returns, infiltration of irrigation water, underutilized water rights and dewatering of storage facilities at the end of irrigation season. This approach indicates the need for stream gauging to quantify baseflow for comparison to recharge and use estimates.

Additionally, water that infiltrates from unlined reservoirs, leaking domestic water service lines and water used for snow making at Mission Ridge Ski Area is largely returned to the hydrologic system. However, these elements are not quantifiable without monitoring or use data, and were therefore not estimated. The Multi-Purpose Water Storage Assessment in preparation will evaluate the potential benefit of improving water efficiency in storage and conveyance systems.

Section 6 – Future Water Use in WRIA 40A

Anticipated future water use in WRIA 40A relies on several components and assumptions. First, it is important to know the current and projected population of the area. Second, the potential availability of water for future population increases must be assessed, which compares the water balance (the physical availability of groundwater and surface water) to water rights (the legal availability of water) to determine whether additional water is likely to be legally available in the future. Third, in addition to the population projections, several land use factors need to be evaluated such as zoning, suitability of undeveloped land for future development, etc.

6.0 CURRENT AND PROJECTED POPULATION

Chelan County Natural Resource Department provided the following population assessment for use in the WRIA 40A watershed planning process.

Method

Within Chelan County, the US Census Bureau has delineated areas known as County Census Divisions (CCD). The CCD's are sub-divided into census tracts in which the population data were extracted. There are 8 CCD's within the county but they do not follow watershed boundaries. The Malaga CCD includes the areas of Malaga, Wenatchee Heights, Three Lakes and the area south of Three Lakes to the County line. WRIA 40A includes Malaga, Wenatchee Heights, Three Lakes and a small section of South Wenatchee. The WRIA does not include the Colockum Creek drainage which is included in the Malaga CCD. In order to accurately estimate the current population and project the future population growth in the WRIA, census data were extracted from the Malaga CCD and from census tracts in South Wenatchee based on the WRIA boundary.

Data from the Chelan County Comprehensive Plan, the US Census Bureau and the Washington State Office of Financial Management were used in the population projections. Chelan County parcel data was used to determine the number of domestic households in the WRIA. The Washington State Office of Financial Management provides the county with population projections for each of the County Census Divisions.

The Chelan County Comprehensive Plan states the 2000 Malaga CCD population was 3,506. The 2025 projected population for the CCD is 4,760. This represents a 36% increase from 2000 to 2025 and an annual increase of 1.24%. Since the majority of the WRIA falls within the Malaga CCD these same percentages were used to determine the future WRIA population.

Results

The Chelan County Comprehensive Plan (Chelan County, 2000) states the Malaga (CCD) population projections are as follows.

Year	**2000**	**2025**
Population	3,506	4,760

This represents a 36% increase in population from 2000 to 2025. According to the Comprehensive Plan, county households average 2.62 residents per household. This number is being used for future projections as well.

In order to determine the year 2000 population with WRIA 40A, Census Block data from the Washington Office of Financial Management was extracted using the WRIA 40A boundary. The year 2000 population of WRIA 40A is 3,770.

When the 36 percent population increase projected for the Malaga CCD is applied to this number, the 2025 population projection for WRIA 40A is 5,130. The County calculated the annual population increase at 1.24 percent. Using this rate of increase from the year 2000, the 2006 population of WRIA 40A is estimated at 4,059 residents.

Potential Sources of Error

As a means of checking the accuracy of this number, the County looked at existing buildings within the area. In order to determine domestic water use, the Chelan County parcel data were used to determine the number of existing households within the WRIA. Chelan County classifies households in six different categories. The following are the assumptions that were used to determine the number of households in the WRIA. The results of that evaluation are summarized in **Table 6-1.**

This yields a total of 1,632 households. When the number of households is multiplied by 2.62 people per household it yields a 2006 population of 4,276, which is approximately 5 percent greater than the estimate of 4,059 but is within the margin of error. For the purposes of the WRIA 40A watershed planning, a 2006 population of 4,059 will be used.

Another way of looking at future water demands is to examine the various water purveyors and their projection of future connections. Projections are available for the following.

- Chelan County PUD
- Malaga Water District (MWD) (including Laurel Hills and Dependable Springs)
- Three Lakes
- Stemilt Irrigation District

Current and projected connections are shown in **Table 6-2**.

For planning purposes, it is prudent to assume that Chelan County PUD will grow to provide a maximum of 459 connections. It is also assumed that MWD will serve 587 connections and that Three Lakes will grow to serve 280 connections.

The existing connections of the Stemilt Irrigation District are assumed to continue in the future at the current level of 55 connections.

RH2 has estimated future domestic use based on the estimated 2025 population and a 380 gpd consumption rate.

The 2006 population is 4,059. This equates to 1,549 households at the County-wide average of 2.62 people per household. Performing the same calculation based on the estimated 2025 population of 5,127 yields 1,972 households in WRIA 40A..

Present and future domestic water consumption is shown in **Table 6-3**.

As discussed above, population projections were developed in order to determine current (2006) and future (2025) domestic water needs for WRIA 40A. The following section describes the methodology, data, assumptions and results for the preceding estimates of population growth through 2025. **Table 6-4** shows the population data for WRIA 40A from 2000 to 2025.

Table 6-1
Households in WRIA 40A

Domestic Household Categories	Number of Households Assumed	Total
All other residential	1	60
Single Family Unit	1	1,554
House 2-4 units	3	1
Mobile home parks/courts	1	2
Residential Hotels/Condos	1	12
Vacation and Cabin	1	1
	Total	**1,632**

Table 6-2
Current and Projected Connections

Purveyor	Number of Connections 2006	Number of Connections 2025	Information Source
Chelan PUD	311	459 ERUs in 2022 (Reigert, 2003)	DOH total connections approved
MWD	361/380	587	DOH total approved connections. MWD = 361. MWD + Laurel Hills & Dependable Springs = 380.
Three Lakes	238	280	DOH total approved connections.
Stemilt I.D.	55	55	DOH total approved connections.

Table 6-3
Present and Future Domestic Water Use

PER HOUSEHOLD			**TOTAL FOR WRIA 40A**	
	gal/yr	**afy**	**2006 afy**	**2025 afy**
Potable	73,000	0.22	347	442
Irrigation	65,700	0.20	312	398
Total Use	**138,700**	**0.43**	**659**	**839**

Table 6-4
WRIA 40A Population 2000-2025

Year	WRIA 40A Population	Annual Increase	Annual increase in Population
2000	3,770	0.0124	47
2001	3,817	0.0124	47
2002	3,864	0.0124	48
2003	3,912	0.0124	49
2004	3,960	0.0124	49
2005	4,010	0.0124	50
2006	4,059	0.0124	50
2007	4,110	0.0124	51
2008	4,161	0.0124	52
2009	4,212	0.0124	52
2010	4,264	0.0124	53
2011	4,317	0.0124	54
2012	4,371	0.0124	54
3013	4,425	0.0124	55
2014	4,480	0.0124	56
2015	4,535	0.0124	56
2016	4,592	0.0124	57
2017	4,649	0.0124	58
2018	4,706	0.0124	58
2019	4,765	0.0124	59
2020	4,824	0.0124	60
2021	4,884	0.0124	61
2022	4,944	0.0124	61
2023	5,005	0.0124	62
2024	5,067	0.0124	63
2025	5,130	0.0124	64

6.1 WATER RIGHTS CONSIDERATIONS FOR FUTURE USE

Water use and water rights data indicate that water rights have been issued for more instantaneous quantity of water and for more acre-feet of water than is generally available in WRIA 40A. This is not unusual in that water rights are often be issued for use in good water year and curtailed in low water years. Therefore, the total rights may exceed the total supply in most years.

Delineation of surface and groundwater uses that are clearly a part of the Columbia River drainage and not WRIA 40A depends on detailed hydrogeologic data not available for this assessment. Direct surface water diversions from the Columbia River have already been identified. Groundwater withdrawals in the lower portions of the WRIA, which may be in direct hydraulic continuity with the Columbia River, still need to be identified and the area that is most appropriately considered part of the Columbia River needs to be delineated. When that is done, water rights and uses pertaining to the Columbia River system will be separated from the remainder of the rights for WRIA 40A, and would help bring the water use numbers and the water right allocation numbers closer together.

The Department of Ecology recently started work on the Columbia River Water Management Program, which intends to develop a management plan that:

- Invests in storage, conservation and improved water management practices on the Columbia River;
- Distributes water to both out-of-stream and in-stream needs, getting it to the right place at the right time;
- Allows for creativity and flexibility in achieving water resource solutions through regional agreements;
- Sustains growing communities and a healthy economy, while meeting the needs of fish and healthy watersheds.

The water supply inventory for this program will evaluate the amount of water diverted for out-of-stream uses in Washington and Oregon within a one-mile corridor of the river from the Bonneville Dam to the Canadian border in Stevens County. The results of this evaluation need to be examined for the WRIA 40A study area to ensure a consistent treatment of water rights and water use in that 1-mile corridor.

It should be noted that water use technology has changed over the years and, as water use efficiency has increased, the amount of water actually used may have decreased. Therefore, there may be a number of water rights in the basin whose users no longer require the full allocated quantity of water. This, too, can account for the differences between actual use and water rights allocated quantities.

6.1.1 Potential Regional Water System Expansion

There has been considerable interest in the potential expansion of the Wenatchee-area regional water system in the near future. Such an expansion would shape the location and rate of development in WRIA 40A. Given the historic difficulty of obtaining new water rights and the likelihood that the Columbia River is the most likely source of any significant quantities of new water, the expansion of the regional water system becomes more likely in the future.

6.1.2 Other Potential Development

Recently, the Washington Department of Natural Resources (WADNR) has been evaluating the potential for a "land swap" in which WADNR would trade four sections of land in Township 21 North, Range 20 E, (sections 16, 20, 22 and 28) in exchange for approximately 30 sections of land south of Naneum Ridge in Kittitas County. This is part of the Central Cascade Land Exchange. If this trade is made, the new owner of the four sections would be the Western Pacific Timber Company. There is local speculation that this land would then be developed into a resort or some other form of "high-end" development. Irrigators and land owners expressed concern about decreased water quantity, degraded water quality and losing access to the land on which many of their irrigation infrastructure elements are located and their ability to further develop water supplies in the future. Additionally, irrigators and land owners expressed concerns about the increased risk from wildfire resulting from potential development of the upper elevations of WRIA 40A. A major wildfire in this area would dramatically alter hydrology in the watershed and negatively impact irrigation system operations. Although this trade is opposed by many irrigation districts, outdoor groups, Chelan County Natural Resource Department and local State and County elected officials including the Chelan County Commissioners, the outcome is uncertain. If approved, the impact of this change in ownership will need to be fully evaluated.

6.2 FUTURE LAND USE CONSIDERATIONS

Within WRIA 40A, there are lands that are zoned and suitable for both industrial use and irrigation use. The degree to which these lands will be developed in the future and the rate at which that development will occur is difficult to accurately predict.

Method

Potential growth of irrigated lands in WRIA 40A was estimated from the map of current crop cover (**Figure 4-2**), Chelan County zoning information, an air photo and a digital elevation model (DEM) using GIS. The DEM was used to examine the maximum land surface gradient, or slope, in regions currently used for tree crop. The vast majority of tree crop is planted in areas having slopes less than 15 degrees. Potential crop growth areas were identified as locations where crops currently do not exist, having less than 15 degrees slope, are mostly non-forested and zoned for commercial agriculture or Rural Residential/Resource. The Malaga LAMIRD Designation (Chelan County, 2006) was taken into consideration and lands currently inside of the loop formed by West Malaga Road were excluded. Using the irrigation application rate described in **Section 4**, an annual irrigation volume for potential irrigation growth was estimated. The conversion of agricultural lands to other uses is addressed below, but an analysis of its impact was not conducted due to current land-use zoning that gives little indication of substantial departures from current land uses.

Results

Approximately 2,700 acres meet the criteria described above. If these lands were fully developed into agricultural lands, having similar irrigation requirements as existing agricultural lands, the annual demand for irrigation water during an average year would increase by about 9,580 acre-feet (**Tables 5-2** and **6-5**). In the absence of additional water imported from outside the basin, and not accounting for baseflow contributions to streamflow in the estimate for recharge, additional irrigation demand would create a deficit of water during an average precipitation and temperature year. Additional demand might be met in a wet/cool year which is estimated to have about 11,800 acre-feet of surplus runoff (**Table5-4**). Increased irrigation will also increase the return of irrigation water as a result of sprinkler head inefficiency.

Table 6-5
Water Balance - Future Conditions[1], Average Year

Input	acre-feet	inches	Percent of Precipitation	
Precipitation	86,520	21.0	100	
Surface Water Import[2]	5,460	1.3	6.3	
Groundwater Import[2]	130	<0.1	0.2	
subtotal	92,110	22.4	106.5	
Output				
Evapotranspiration	44,900	10.9	51.9	
Recharge	30,690	7.5	35.5	
Runoff		*see below*		
Domestic Irrigation	400	0.1	0.5	
Crop Irrigation	29,010	7.1	33.5	
Free Water Evaporation	470	0.1	0.5	
Industrial Use	260	0.1	0.3	
subtotal	105,730	25.7	122.3	
Return				
Septic	510	0.1	0.6	
Irrigation Infiltration	4,450	1.1	5.1	
subtotal	4,960	1.2	5.7	
				Flow (cfs)[3]
Balance (runoff)	-8,660	-2.1	-10.1	-12

Notes:
1. Components of the water balance were estimated using existing data. Because there are no continuous streamflow data available, runoff was estimated to be the balance after all other components were estimated.

2. Assumes no increase in water imported from outside WRIA 40A
3. Runoff is estimated average annual combined flow for Squilchuck and Stemilt creeks.

Potential Sources of Error

The estimate for future irrigation demand is based solely on the potential to convert lands from current use to irrigated agriculture. This estimate assumes that irrigation can be delivered to all parcels, that the owners of these parcels desire to place these lands in tree crop and that water rights are available. For these reasons, and because most of the contiguous parcels of relatively flat, non-forested land within areas zoned as commercial agriculture are already used for tree crop, this estimate serves as a maximum. In making this estimate, it is also assumed that average sprinkler head efficiency for WRIA 40A will remain at 80 percent. It is also assumed that no additional water will be imported from outside of WRIA 40A.

While it is possible to assign a reasonable water duty to future irrigated lands, there is no way to accurately predict how much new land will come under irrigation or when. One of the primary reasons for this is the uncertainty surrounding the availability of new water rights from sources within WRIA 40A, another reason is the uncertainty of how the Department of Ecology's Columbia River Water Management Program will affect future water availability in basins bordering the Columbia River.

Forecasting future industrial use poses similar problems. Industrial water use varies widely depending on the nature and scope of the industrial operation. Without knowledge of what is being considered, it is impossible to accurately predict future industrial water use. Also, because of the uncertainty of water rights discussed above, it is unclear whether additional water will be available for such uses from sources within WRIA 40A. Future industrial uses may need to obtain water from the Columbia River and the status of such potential supplies is dependent on the results of the Columbia River Management Program as well.

Section 7 – Summary and Recommendations

This section summarizes key findings of the water quantity assessment, identifies gaps in data that would improve understanding of the quantity and availability of water, and recommends actions for data collection and analysis that would improve water management in the watershed.

Summary of the Water Resources

Table 7-1 compiles the sources of water, types of use and water rights for WRIA 40A. This summary provides reasonable estimates for the quantities of water in the watershed, indicates how water sources are appropriated and used, and the potential availability of water to meet future demands. Previous sections described the highly variable natural and artificial characteristics of the sources and distribution of water in the watershed, and the assumptions and potential error in the calculations to estimate water quantities in WRIA 40A.

Table 7-1
Summary of Water Resources in WRIA 40A

Sources of Water		Quantity (average year);(afy)
	Imported	5,460
	Runoff[1]	10,930
	Recharge[2]	7,670
	TOTAL[3]	**24,060**
Uses of Water		
Groundwater	Domestic	500
	Commercial	260
	Irrigation[4]	0
Surface Water	Domestic	25
	Commercial	6
	Irrigation	13,970
Imported	Domestic	130
	Commercial	<0.1
	Irrigation	5,460
	TOTAL	**20,350**
Water Rights		
	Surface Water	19,258
	Groundwater[5]	5,146
	Reservoir	3,253
	TOTAL	**27,657**

Notes:
[1] Runoff is for natural conditions (**Table 5-1**)
[2] Assumes 25% of total recharge (total recharge equals 30,690 acre-feet) is available for groundwater withdrawal or seeps to streams as baseflow.
[3] Does not include domestic or irrigation return flow, which may not be available for use at the time or location of demand.
[4] Assumed to be zero, although water rights indicate 400 acres under irrigation using groundwater sources.
[5] Assumed to be used primarily for potable and industrial (non-irrigation) use.

The total water readily available for use in the watershed is the sum of surface water runoff and imported water, or 16,390 acre-feet. An additional, although uncertain, amount of groundwater is also available for use. This amount is the percentage of groundwater recharge that may be economically withdrawn from wells or that naturally seeps into streams as baseflow. As discussed in **Section 2**, the location of readily available groundwater resources in WRIA 40A is difficult to predict, although the greatest potential lies within flood units in lower elevation Malaga sub-basin. Assuming that 25 percent of groundwater recharge is available, the total amount of water in the watershed physically available for withdrawal is approximately 24,000 acre-feet.

Water use in an average year is estimated at 20,350 acre-feet. In comparison, the combined annual surface water, groundwater and reservoir rights that appropriate and use water is 27,657 acre-feet, which exceeds the average water use by 36 percent and the physical water availability by 15 percent. This relationship between water right and water use or physical availability could lead to conclusions that: 1) water use is underestimated and withdrawn at a non-sustainable rate; 2) the physical availability of water and water use is underestimated and actual use is closer to paper water rights; or 3) that water rights are not used to their full extent. The reality for WRIA 40A is that water flows in streams at nearly all times (at low and variable rates), and that normal water diversion and use of irrigation water does not exceed annual replacement. However, the difference between estimated average water availability and average water use is less than 4,000 acre-feet, indicating that at the very least, imported water is vital to sustaining current water use, and that average water use is nearly equal to average water availability. These conclusions are probably considered general knowledge to those that depend on and manage water in WRIA 40A. This quantity assessment confirms the general knowledge of water use, improves the understanding of water relationships in the watershed and also identifies the need for additional water data to better manage the water resources of WRIA 40A.

Potential Sources of Water to Meet Demand

The assessment indicates that water use in the watershed is relatively efficient and that multiple approaches would be required to obtain water for future demands. This assessment will guide the Multi-Purpose Water Storage Assessment and Phase 3 Watershed Planning by providing the conceptual understanding of water quantities and relationships in WRIA 40A to evaluate opportunities and benefits for water management alternatives. These alternatives may include:

- In-basin conservation – the potential efficiency improvements for storage, conveyance and use;
- Import water – availability of additional water for import from adjacent watersheds or the Columbia River;
- Groundwater withdrawal – the regions most likely to support additional groundwater withdrawal, and conversely, the regions that lack dependable groundwater supply;
- Runoff capture – whether high flow runoff could be managed for additional storage or groundwater recharge; and/or
- Additional storage– whether new reservoirs could be created to store surplus water. Potential reservoirs may include traditional above-ground storage, or innovative storage using aquifers or snow-making;
- Extending or shifting storage facility fill times to better coincide with peak runoff.

Data Gaps and Recommendations

The previous sections indicated the lack of data available to quantify water resources in WRIA 40A. The following summarizes significant data needs and potential methods to obtain these data.

Physical Water Availability

1. Stream gauges that measure streamflow in upper and lower Squilchuck and Stemilt Creeks will provide data to improve the understanding of the relationship between precipitation, runoff, irrigation return flow and baseflow. These monitoring stations, in junction with stream diversion monitoring, would identify the exchange between surface water and groundwater. The monitoring would also support the evaluation of the effects of land use on streamflow, stormwater runoff and water quality. Land uses that would affect runoff include forestry, residential and commercial development, re-zoning and irrigation practices.

2. Groundwater well elevation monitoring would provide data to quantify seasonal fluctuations in groundwater levels for comparison to precipitation and infiltration rates. These data would improve the understanding and estimates of groundwater recharge, flow and groundwater availability.

3. Groundwater elevation monitoring within 1 mile of the Columbia River would help delineate the hydraulic boundary between Columbia River and WRIA 40A. This would identify the sources of groundwater and establish the availability of groundwater in the Malaga sub-basin.

4. Weather stations at mid-watershed elevations to measure precipitation and temperature would improve the understanding of the relationship between elevation and precipitation and support estimates of runoff. Soil moisture can also be measured at a mid-elevation station to evaluate actual crop irrigation requirements at higher elevations. Recall that the irrigation demand estimate is based on data from low elevations. Soil moisture data can also be used to improve the AET estimate by using physically based (i.e. Penman-Monteith), instead of empirical, methods. Small differences in estimated precipitation and evapotranspiration can cause substantial differences in estimates of runoff and available water.

5. Improving the monitoring and communication of water quantity imported into WRIA 40A would refine the estimates of available water and future water demand.

Water Use

1. Voluntary monitoring and reporting of storage levels and conveyance flows would improve the understanding and adoption of irrigation storage and conveyance efficiency.

2. Voluntary stream diversion monitoring and reporting program to account for out-of-stream water use would improve estimates of available water. Irrigation districts would be able to obtain funds to install measuring weirs and use them to make regular inflow/outflow measurements for their own records and to report to CCNR for data collection.

3. Voluntary monitoring and reporting program for commercial and industrial use to account for out-of-stream water use would improve estimates of available water.

Water Rights

1. Resolving the discrepancies between the number of water rights points of diversion shown on the Water Rights Map Points of Diversion and those observed by WDFW in the field during the barrier survey would improve the estimate of total water diversion and water availability.

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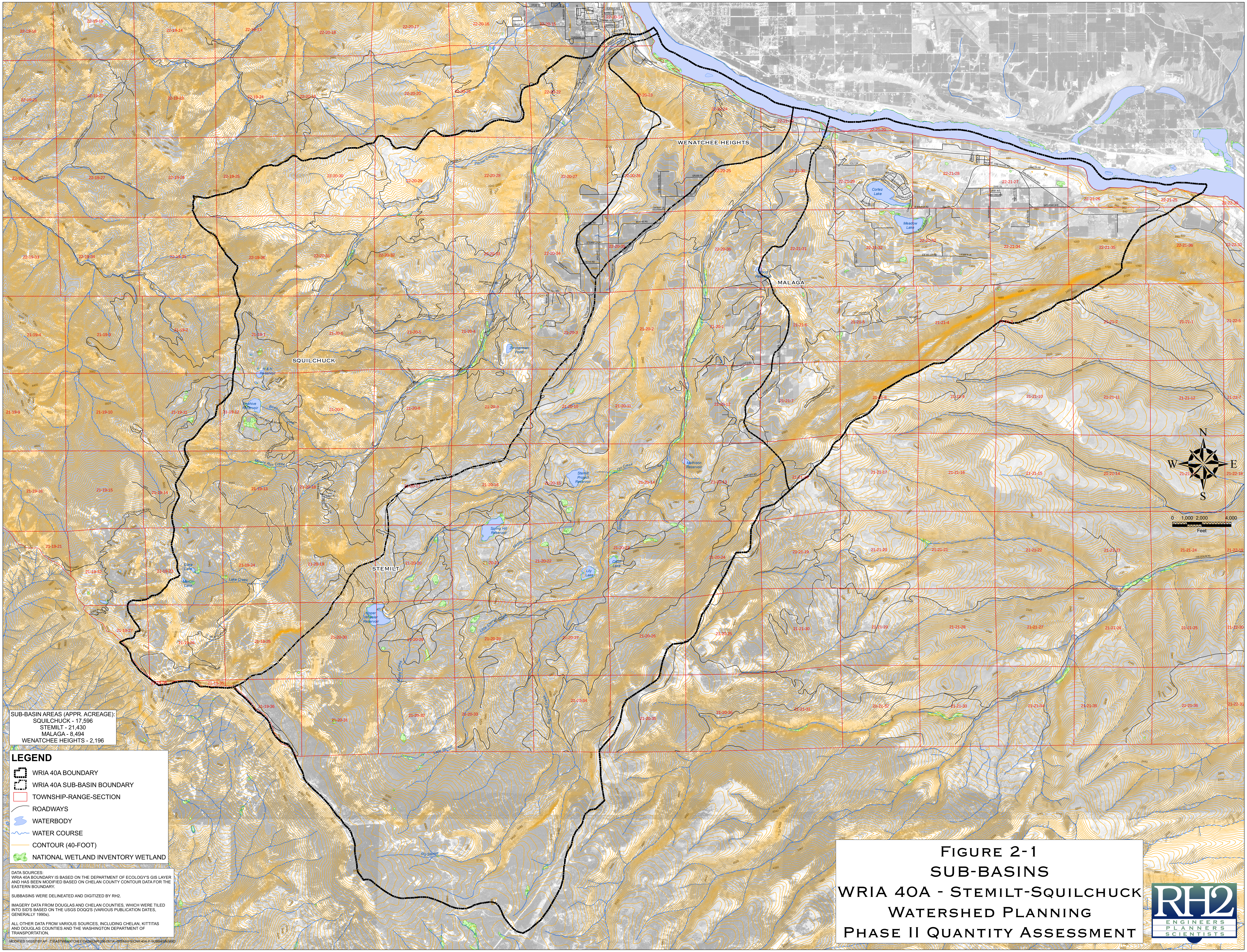

Figure 2-1
SUB-BASINS
WRIA 40A - Stemilt-Squilchuck
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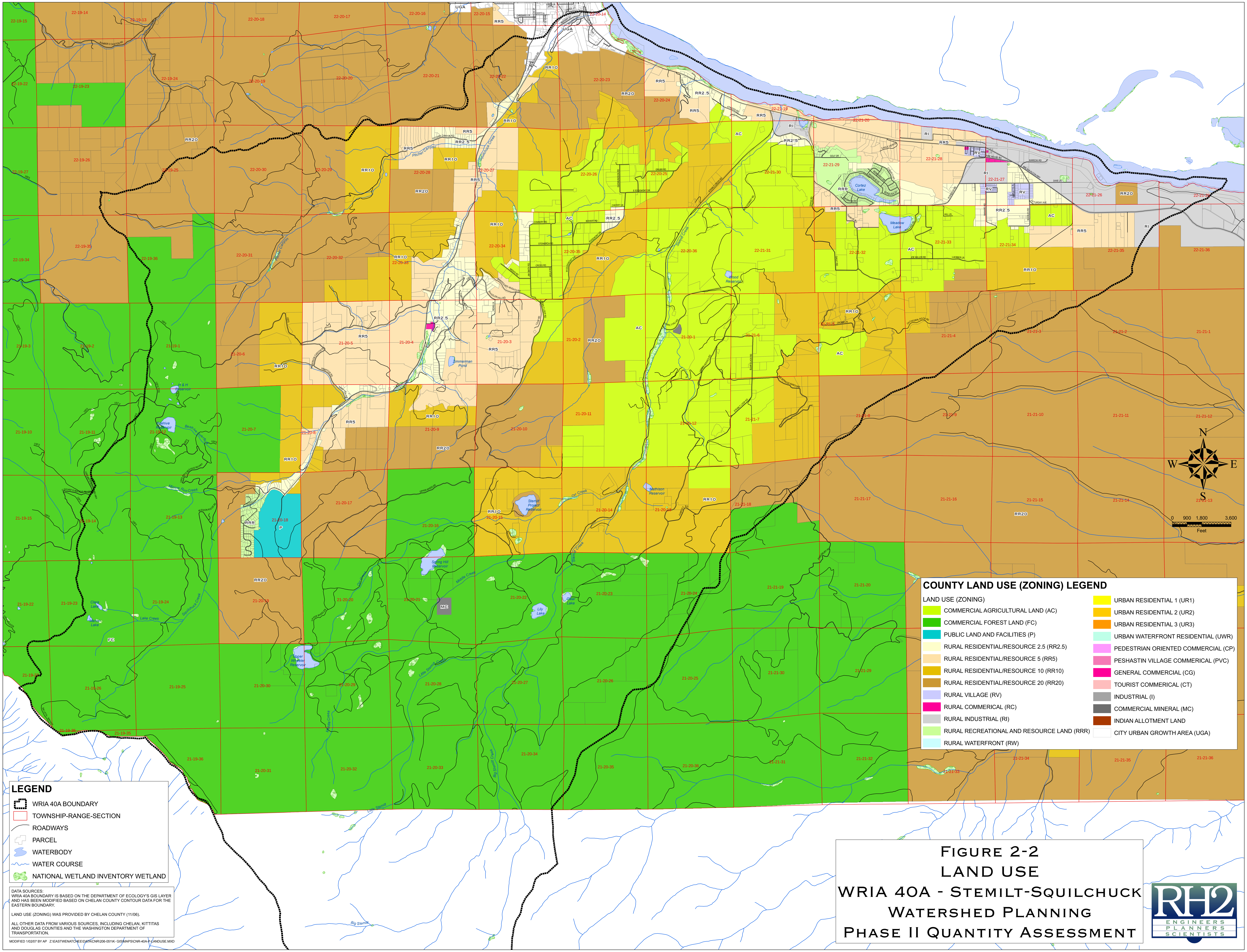

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Annual Precipitation and Temperature
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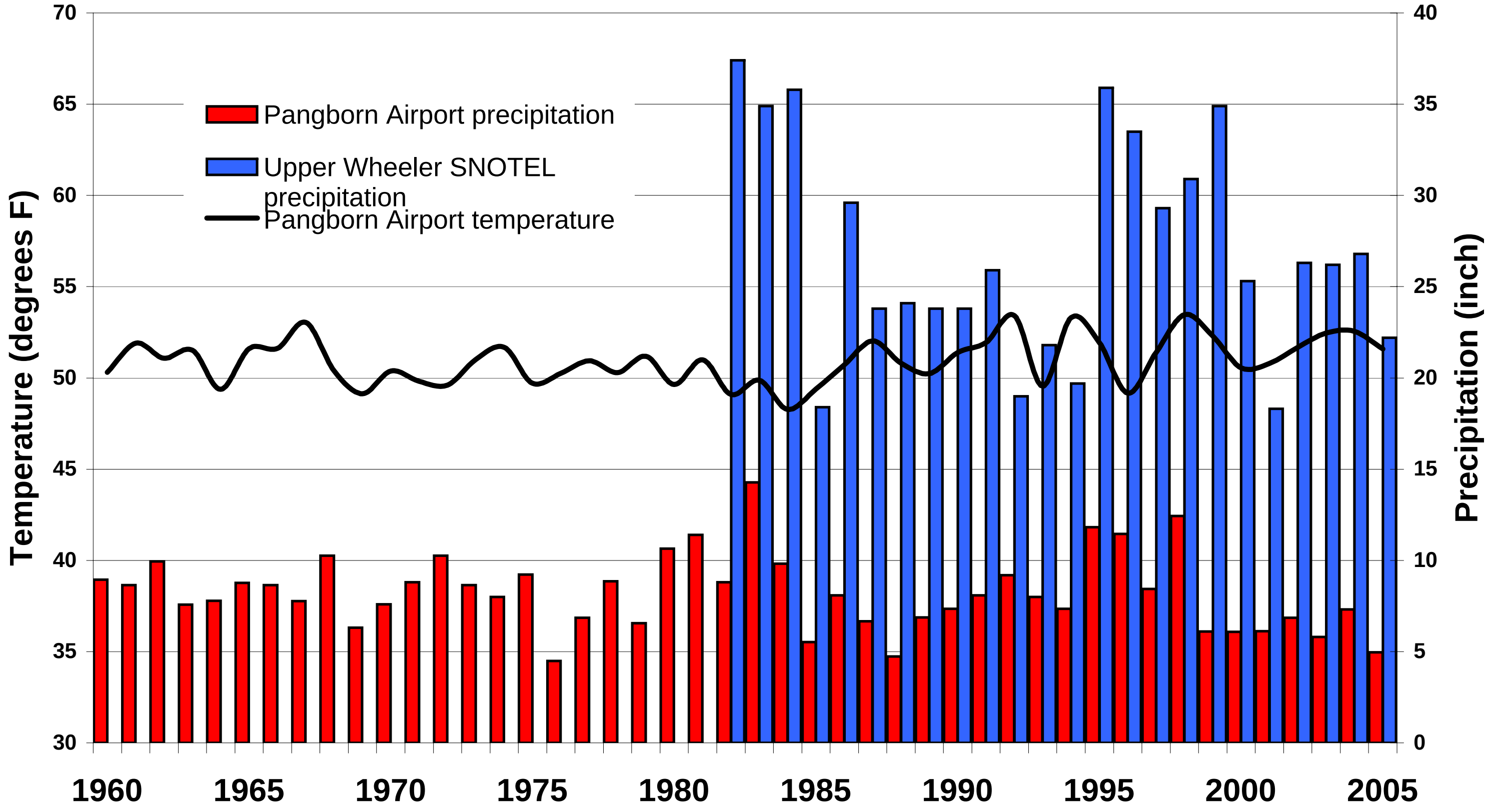
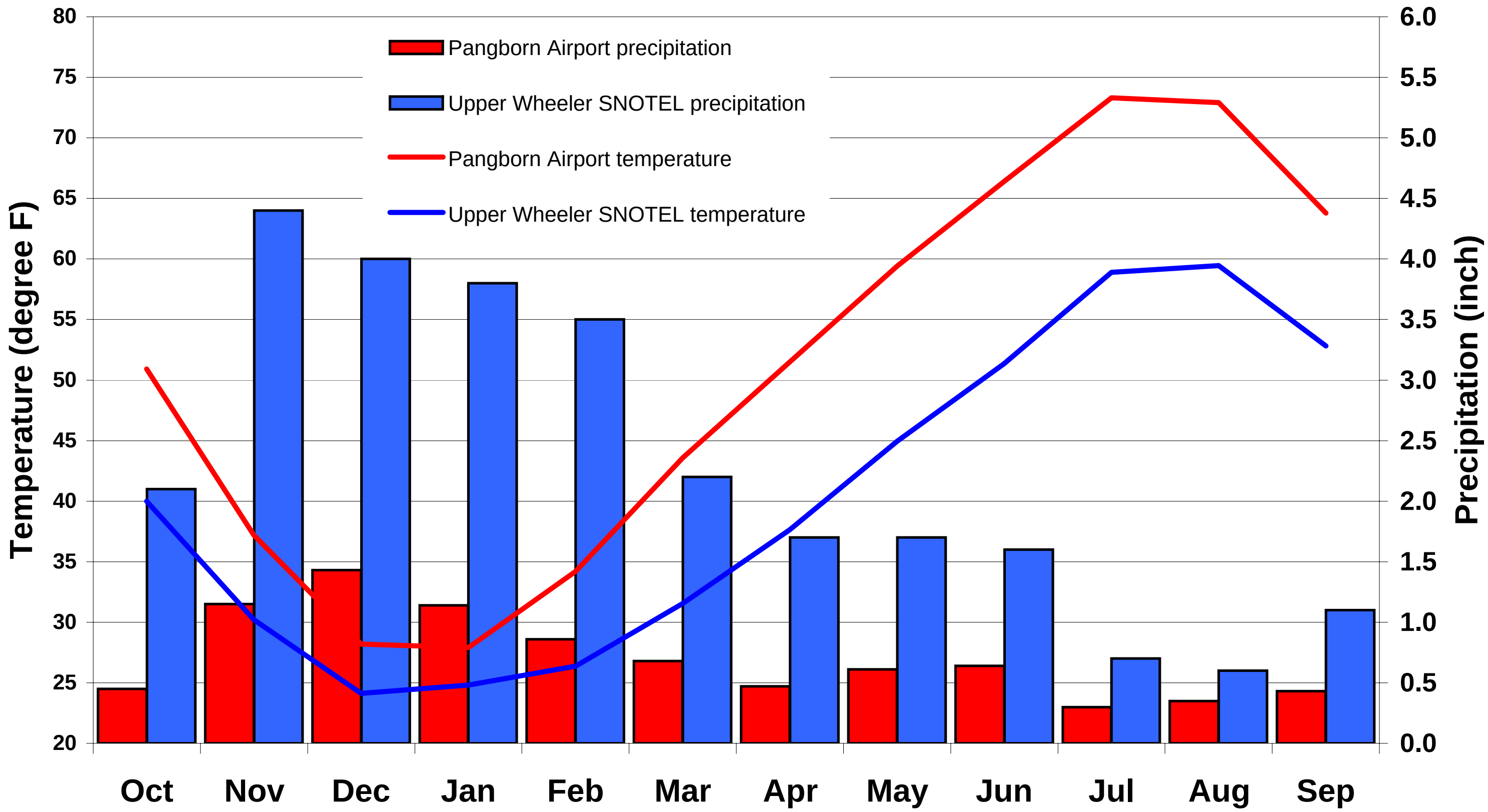


Source: WRCC (2006) for the period 1971-2000 (Pangborn) and
NRCS (2006) for the period 1990-2005 (Upper Wheeler).

Figure 2-4
Average Monthly Precipitation & Temperature
Pangborn Airport and Upper Wheeler SNOTEL
WRIA 40A - STEMILT-SQUILCHUCK WATERSHED PLANNING PHASE II



Source: WRCC (2006) for the period 1971-2000 (Pangborn) and NRCS (2006) for the period 1990-2005 (Upper Wheeler).

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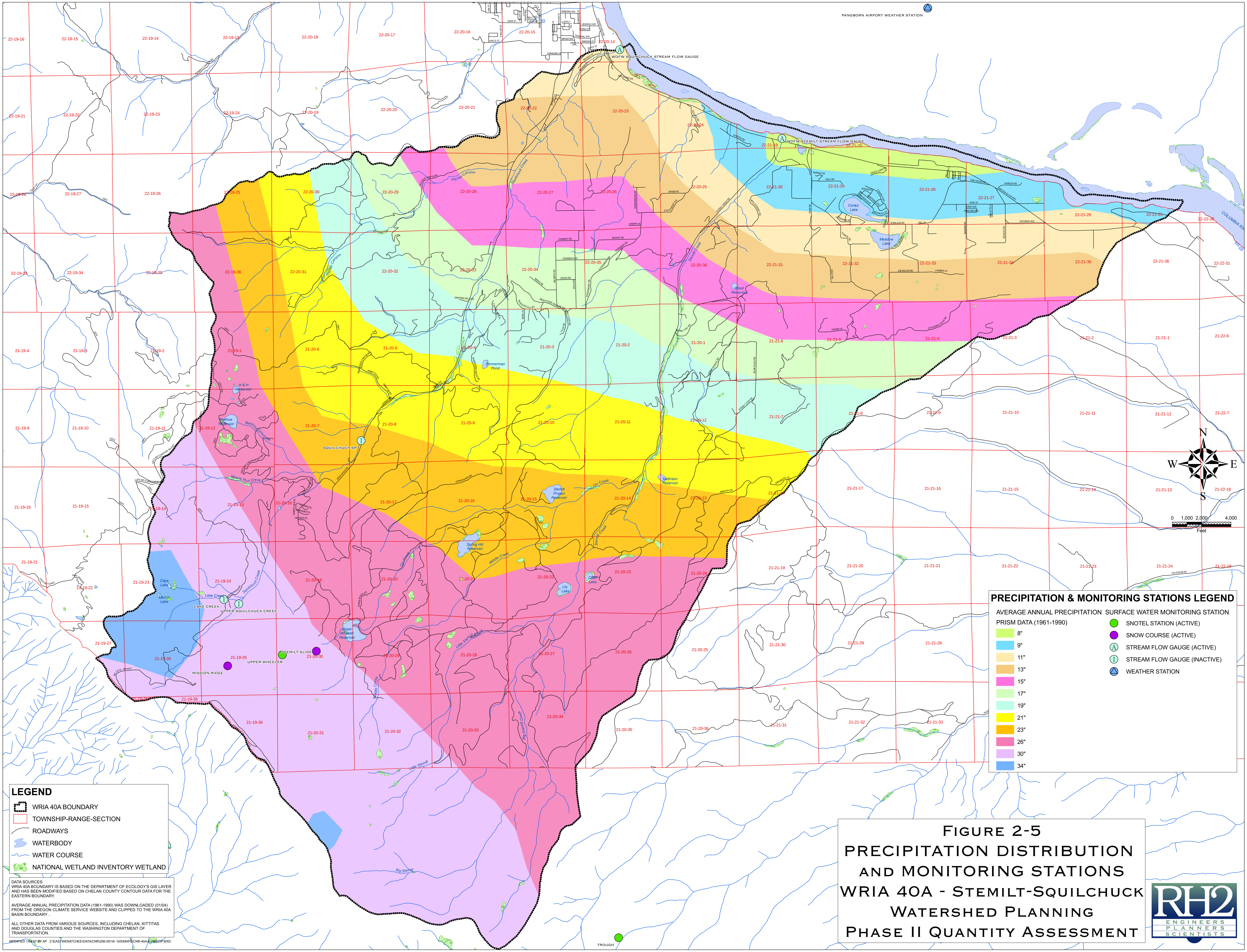

Figure 2-5
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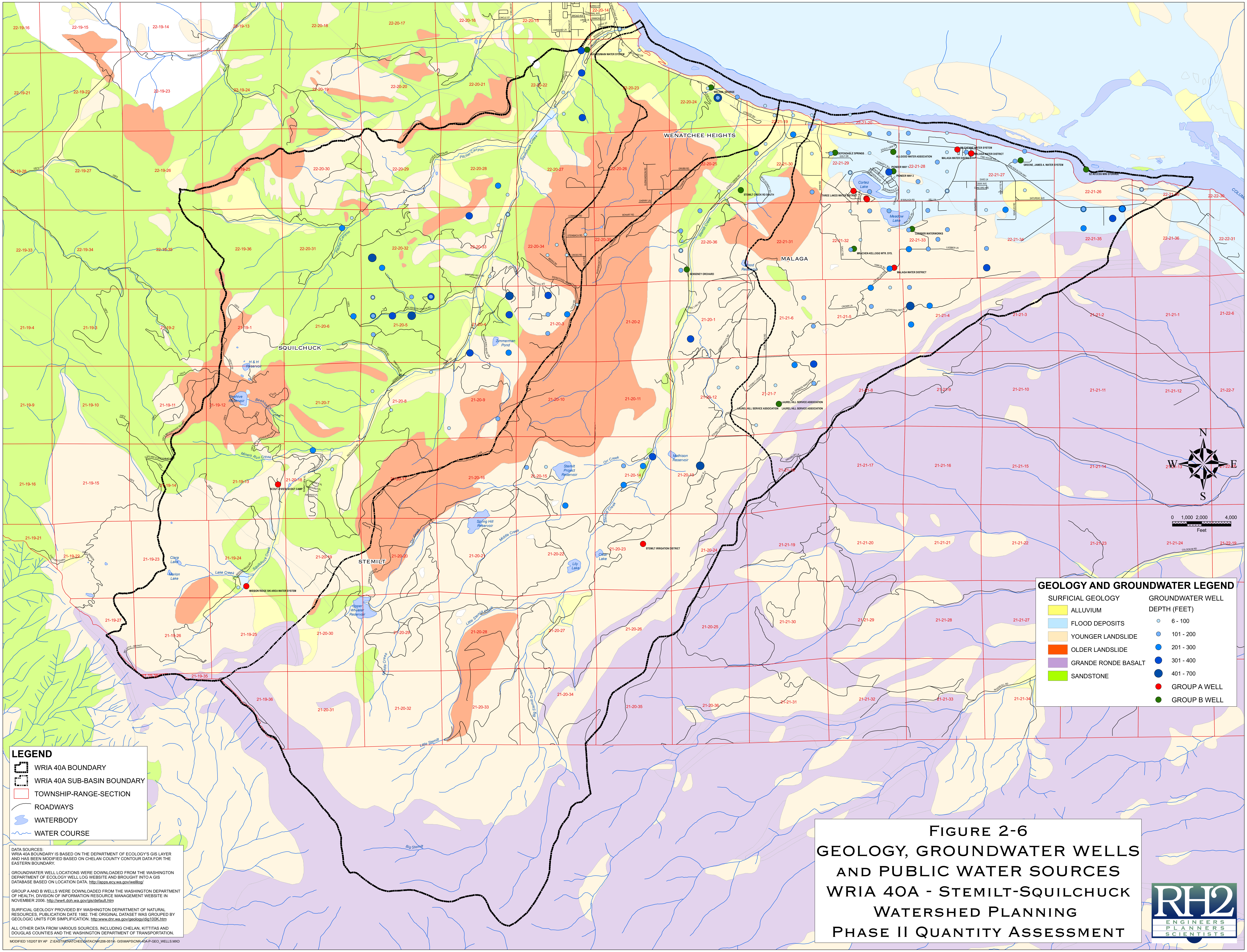

FIGURE 2-6
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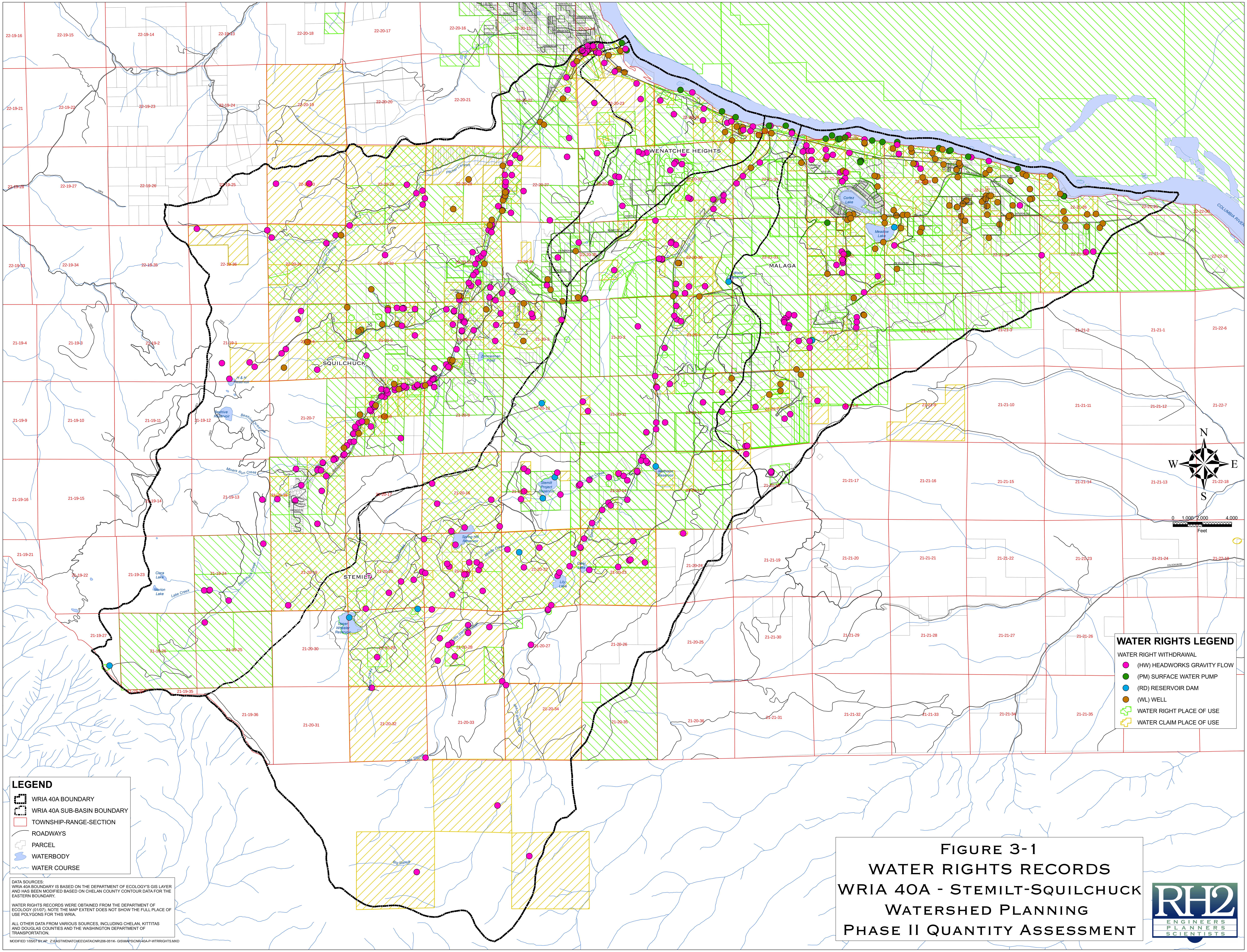

Figure 3-1
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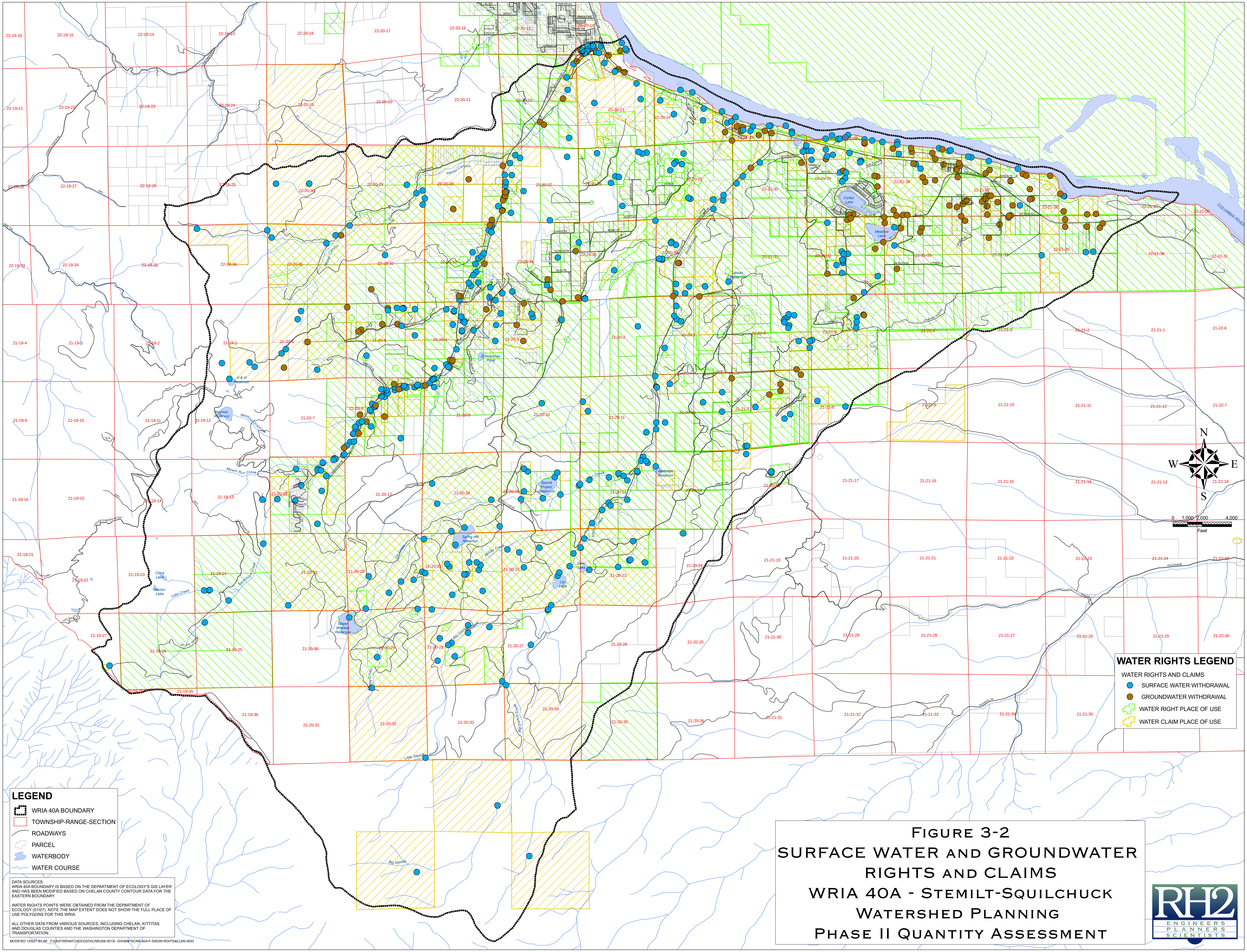

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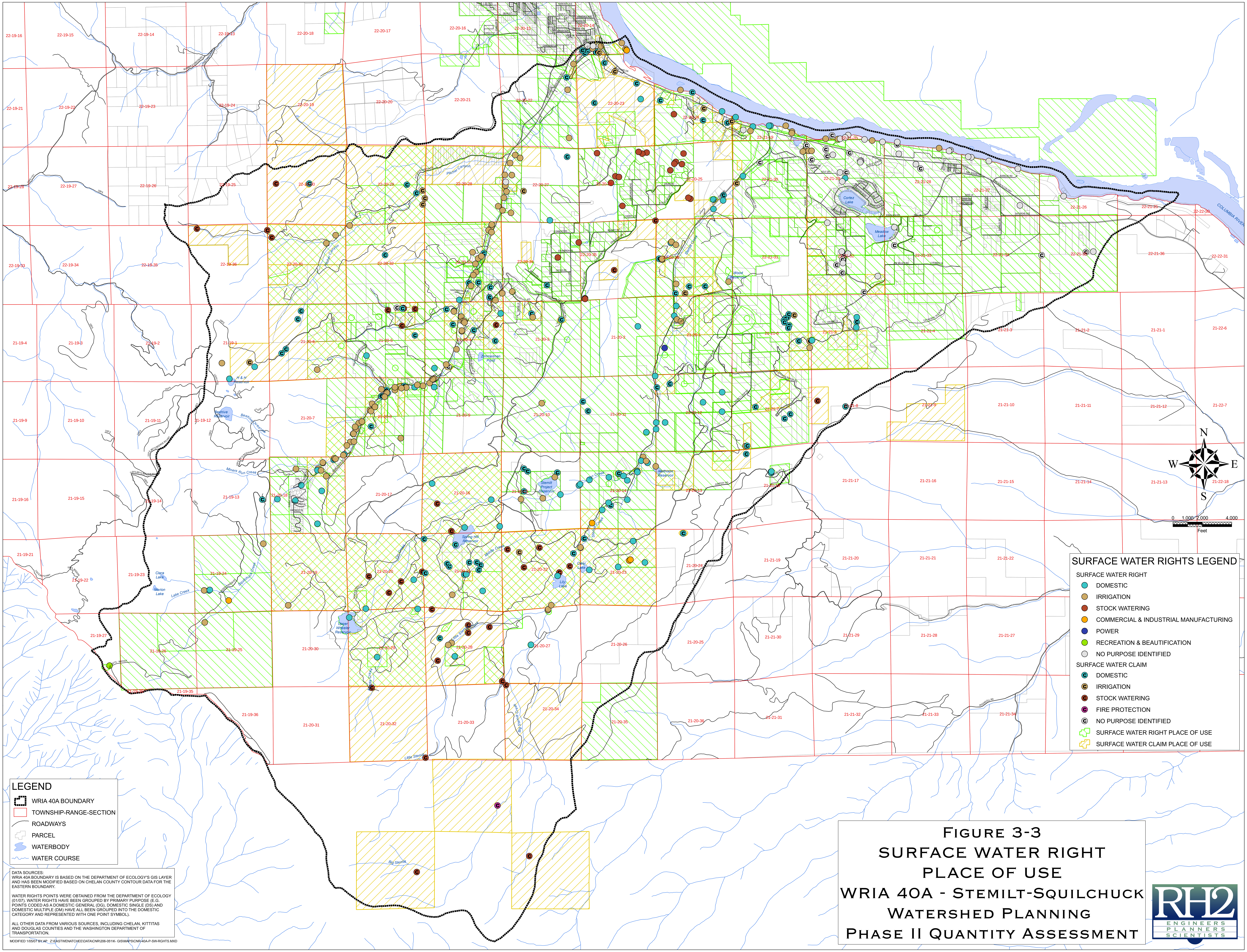

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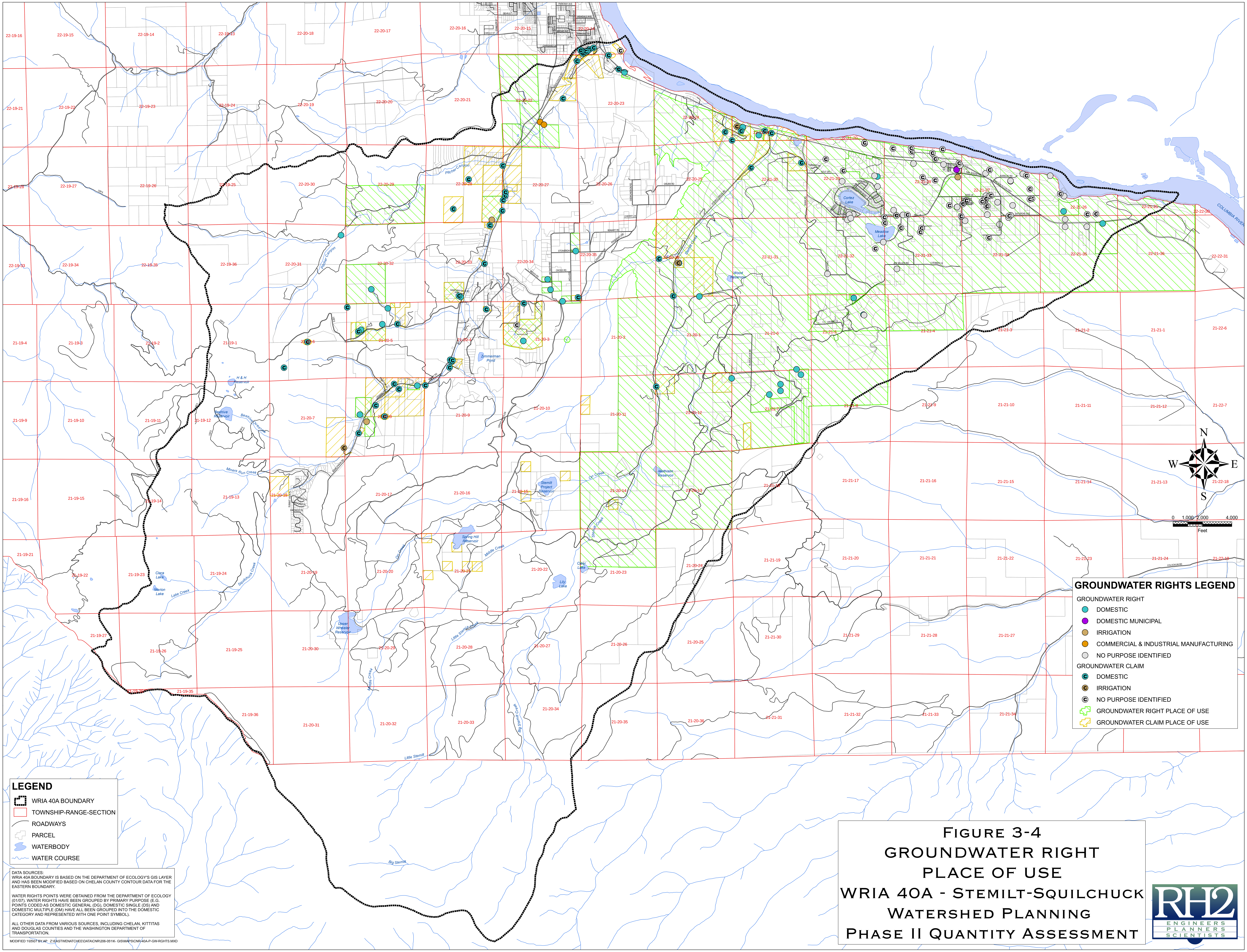

FIGURE 3-4
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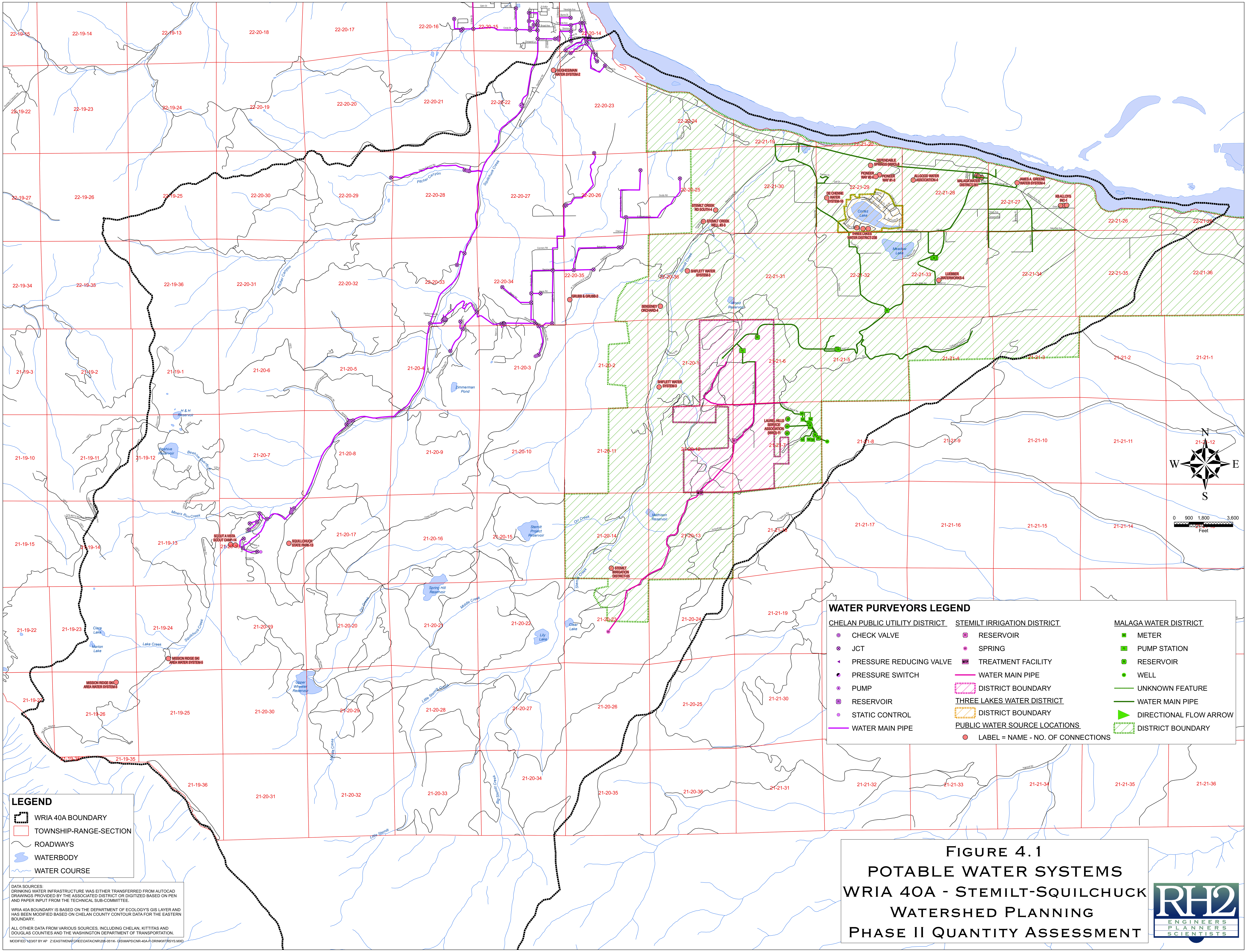

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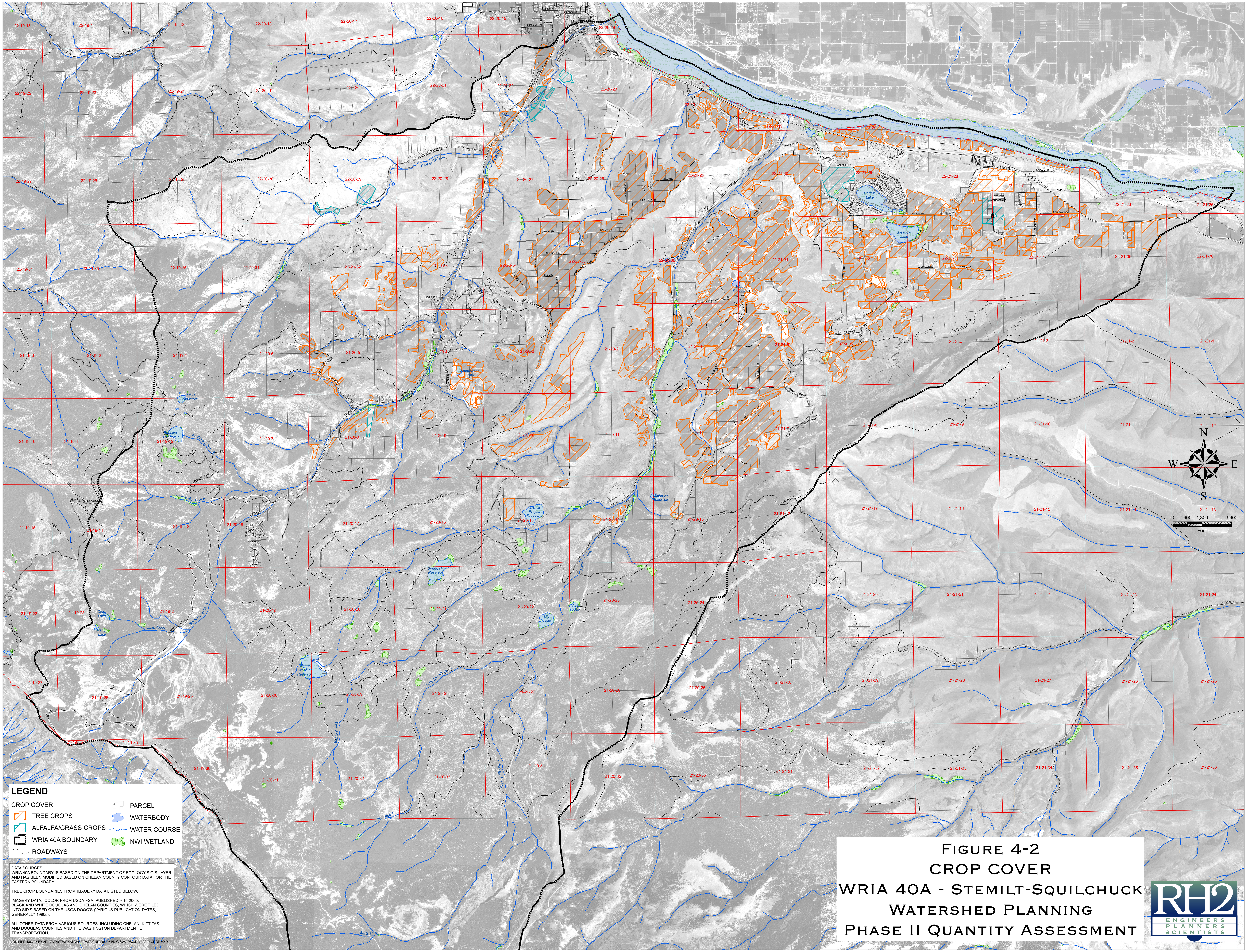

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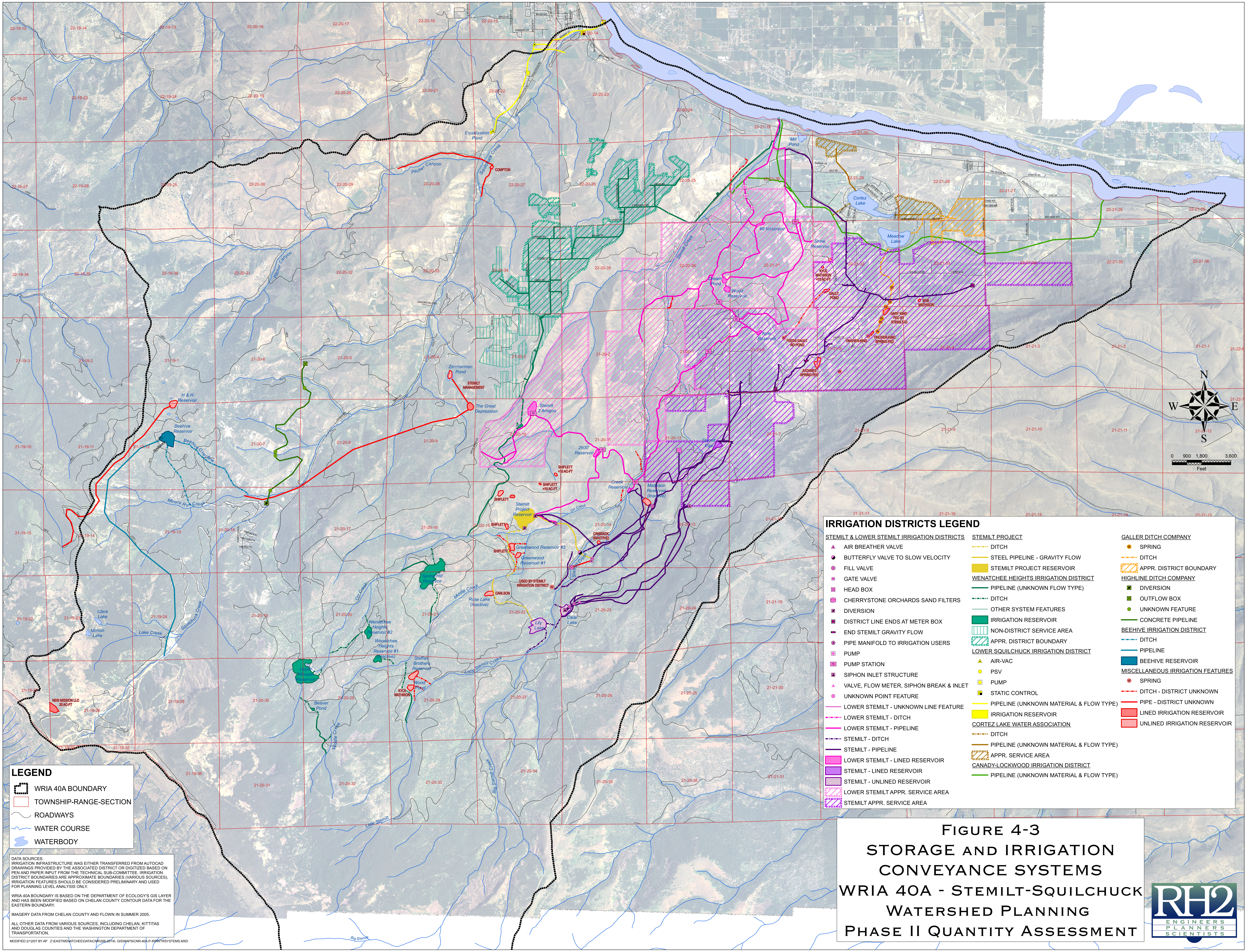

FIGURE 4-3
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FIGURE 5-1
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